ENGINEERING FACTORS RELATING TO THE PRODUCTION OF SMOKELESS FUEL, OIL AND GAS FROM ROCKY MOUNTAIN COALS BY LOW-TEMPERATURE CARBONIZATION

by

Geo. W. Carter

A thesis submitted to the Faculty of the University of Utah in partial fulfillment of the requirements for the degree of Master of Science.

May 15, 1934

Approved by _____

SUCCESS

'Tis the coward who quits to misfortune,
'Tis the knave who changes each day,
'Tis the fool who wins half the battle,
Then throws all his chances away.

There is little in life but labor,
And tomorrow may find that a dream;
Success is the bride of Endeavor,
And luck--but a meteor's gleam.

The time to succeed is when others,
Discouraged, show traces of tire;
The battle is fought in the homestretch--
And won--'twixt the flag and the wire.

John Trotwood Moore.

FOREWORD

The general subject of coal-processing with a view toward the complete elimination of smoke, might well be applied to any American city with a smoke problem. The studies and the accompanying discussions presented herein pertain to the coals of the Rocky Mountain Coal Province with particular attention to the coals of Utah.

Because Salt Lake City is now confronted with an extremely serious smoke problem, and because this work was done at the University of Utah which is located in Salt Lake City, this thesis has been written with the idea of proving what can be done via coal-processing for Salt Lake City in order to completely free it from the harmful smoke screen.

This investigation is a continuation of, and has been aided by the very extensive engineering and economic studies of Utah's coals made by the Federal Government and the State of Utah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

The writer wishes to express his sincere gratitude for the valuable assistance of Mr. S. Clark Jacobsen, who, as an undergraduate student in Mechanical Engineering, cooperated to the fullest extent in designing and erecting the coal-treating plant and auxiliaries, and in conducting the coal-processing studies.

I am greatly indebted to Mr. L. C. Karrick, former federal government fuels technologist, for his scholarly advice and material aid in the designing and the operation of the coal-processing plant, and for his assistance in the analysis of existing and experimental data. Mr. Karrick has also willingly allowed the free use of his patented developments in the field of coal-processing as an extremely valuable and basic asset to this present work.

Furthermore I wish to acknowledge the valuable support and cooperation extended by Professor E. H. Beckstrand, Head of the Department of Mechanical Engineering. I am also greatly indebted to the Engineering Experiment Station of the University of Utah for the fellowship given me, and to the local station of the United States Bureau of Mines. Moreover, the Civil Works Administration has been of aid in providing two men to assist with the work.

I appreciate the cooperation of the coal producers and

retailers who have willingly furnished coal samples for the carbonizing studies.

The work has also been greatly aided by the assistance of Dean R. B. Ketchum of the School of Mines and Engineering, Mr. J. Billeter, Chief Smoke Inspector of Salt Lake City, Miss Dorothy E. Dixon, Librarian of the University Engineering Library, Mr. C. E. Ohrn of the Research Department of Mines and Metallurgy, the chemists of the Gasoline and Oil Testing Laboratory of the Utah State Road Commission, and many others. The writer also appreciates the cooperation of Dr. Cowles in making the coal analyses.

ENGINEERING FACTORS RELATING TO THE PRODUCTION OF SMOKELESS FUEL, OIL AND GAS FROM ROCKY MOUNTAIN COALS BY LOW-TEMPERATURE CARBONIZATION

INTRODUCTION

One-hundred and forty-eight human souls in the small town of Winter Quarters near Omaha, set out on April 7, 1847 to find a new place under the sun where there would be no religious persecution. On July 24th, one-hundred and nine days after the arduous trek was begun, this hardy band of Mormon pioneers stood at the mouth of Emigration canyon and heard their great leader, Brigham Young, say, "This is the right place, drive on." (1) Of this historic incident, Orson Pratt wrote: (2)

> "After traveling six miles through a deep ravine ending with the canyon, we came in full view of the valley of Great Salt Lake.
>
> . . . . . .
>
> "We gazed in wonder and admiration upon the vast valley before us, with the water of Great Salt Lake glistening in the sun, mountains towering to the skies, and streams of pure water running through the beautiful valley. It was the grandest view we had ever seen till this moment."

---

(1) References made to the published data will be found in the Bibliography at the end of this report.

And now, eighty-seven years later, from the same place where Brigham Young uttered his famous words, one views a scene much changed. For a great part of the time one can not discern the beautiful handiwork wrought there by Mother Nature, for it is now obscured by the presence of a man-made, opaque blanket of smoke which completely covers the valley below.

Alas, this picturesque locality, with its waters of Great Salt Lake that rarely glisten in the sun, is buried beneath that sea of smoke, its people living in an atmosphere polluted with soot and noxious vapors and robbed of a full proportion of the health-giving rays of the sun.

. . . . . .

Cause of the Smoke Problem. We are all aware of the obvious fact that smoke is caused by the imperfect burning of bituminous or soft coal. More specifically, when certain carbonaceous substances which are present in the coal, break down into the more common combinations of carbon, hydrogen and oxygen during the ordinary process of combustion, carbon and tars are formed in a finely divided state and are carried through the chimneys into the atmosphere as smoke. Consequently there is created a smoke problem of great magnitude common today in the thousands of coal-burning cities of the United States.

The Various Ill Effects of Smoke. A person breathing at a normal rate consumes [3] by weight about six times as much air as the minimum of solid and liquid nourishment required to sustain him. Air is vital to our existence; so much so, that, without it we could live but a few minutes. Obviously then, the air we breathe should be as pure and as free from contamination as possible.

What are the ingredients of smoke and to what extent do they pollute the atmosphere?

Azbe [4] says that "the aggregated minute carbon particles that constitute soot would be dirty, but otherwise not particularly objectionable if they were not intercharged with adherent liquid tar, with acids of sulphurous nature, and with other harmful substances." What one might easily find in the air of his community can be seen from inspection of Table I [5] below.

TABLE I

AVERAGES OF NUMEROUS ANALYSES OF CITY AIR

	Milligrams per Cubic Meter					
	Chlorine	Ammonia	Sulphuric Acid	Nitrous Acid	Solids	Carbon Dioxide
Country	0.0253	0.00554	0.059	0.00153	0.049	3.17
Parks	0.0608	0.00881	0.217	0.00466	0.33	3.18
Playgrounds	0.0887	0.01117	0.439	0.00704	0.327	3.18
Residence	0.0833	0.01278	0.417	0.00630	0.678	3.16
Boulevards	0.1498	0.00969	0.624	0.00554	0.697	3.37
Mixed Residences	0.1291	0.01149	0.635	0.0085	0.818	3.21
Industrial	0.1254	0.01437	0.517	0.0065	0.826	3.36
Railroad	0.1394	0.00807	0.681	0.00722	0.821	3.37
Loop	0.2166	0.00585	0.959	0.01414	1.689	3.74

Thus we realize that in addition to the soot and dust which constitute the solid matter in a smoky atmosphere, there are also gases such as carbon monoxide, carbon dioxide, certain sulphur and arsenic compounds, and nitrous and chloric vapors. The most serious of these gases according to Obermeyer, (6) is the sulphur, which has been found to be the cause of many forms of eye trouble, and either the cause or the irritant of asthma, catarrh, and similar ailments.

A medical authority says (7): "The inhalation of carbon particles, irritating fumes and other atmospheric impurities irritates the mucous membrane of the nose and lowers its resistance, thus rendering it liable to acute and chronic infections which may even involve the ear and sinus cavity. Smoke likewise irritates the membranes of the entire respiratory tract; predisposing to pneumonia. The sensitive membranes of the eye are inflamed by gases and particles of carbon, thus increasing the liability to conjunctivitis. The functional efficiency of the eye may also be more or less disabled by the constant irritation of solid particles."

Mr. Obermeyer continues further. "In the United States it has been estimated that a prolonged smoke fog will kill more people in two or three days than automobiles can do in as many months. A health commissioner of Chicago - - - - - estimated that between five and six thousand persons were killed each year by Chicago smoke.

"One city, notorious as a smoke-producer, maintained a death rate from acute lung diseases (excluding tuberculosis) of 35 per 10,000 of population within the age limits of fif-

teen to sixty years. This is more than three times the death rate, on precisely the same basis, as that of a neighboring town in which the smoke is negligible.

"The effects of air pollution are seen even in the prevalence of the common cold, which is said to be responsible for one of the greatest economic losses of the present day.

"Smoke, besides being an agent of heart trouble; aggravates the discomfort of those already suffering from this disease. It increases the distress of those with nervous complaints. It lowers the tone of general health, depresses the mind, and imperils particularly the aged, the young, and the weak. Even though smoke may not be an immediate cause of tuberculosis it is certain that sooty deposits on the lungs and the constant breathing of polluted air are factors in hastening the course of the disease once it has been established."

The Committee of Public Health Relations, of the New York Academy of Medicine, recently asserted (8): "Something is present in soot which irritates the skin and leads to cancer. This substance is now thought to be tar and may be a possible factor in causing cancer of the lung, the incidence of which is apparently increasing."

Then too we are advised (9) that in the winter when we are naturally subjected to a shortage of the vital rays of the sun, "we surround ourselves with a cloud of smoke, fumes, and fine dust, still further reducing the most valuable rays and often obliterating them. Today it is known that sunlight improves body metabolism, that it plays an important part in the

development of immunity, that it raises resistance to local and general infections, that it helps to build haemoglobin, that it improves the functions of the skin, and that it keeps the muscles and nerves in tone."

Obermeyer further states: "The National Conference Board on Sanitation tells us that in one year a city like New York loses 35 per cent of the sunlight that should have been available. On top of this, research workers at Harvard University have estimated that only 20 to 80 per cent of the sunlight that actually filters through the smoke haze can get inside of our buildings, owing to the soot and dust coating that daily accumulates on the windows, even when washed as often as twice a month."

Since we have shown that the ingredients of a smoke-laden atmosphere produce serious results to the human body, it is only logical to expect that they will have ill effects upon inanimate objects as well. Experience has shown this to be true.

The items which describe these effects are listed by Mr. Obermeyer as follows:

1. Injury to buildings, decreasing the life of the structure and increasing the cost of cleaning and maintenance.

2. Destruction of real-estate values, owing to tenants moving to other places.
3. Depreciation of merchandise and increased cost of caring for same - which is ultimately passed on to the consumer.
4. Increased household expenses of which the principal ones include depreciation of interior furnishings, and higher soap, laundry, and dry-cleaning bills.
5. Injury to and destruction of trees and shrubs, plus the cost of replacement.
6. Additional use of artificial lighting in home and business.

According to Obermeyer, "the figure usually quoted to cover the annual bill for smoke in the United States lies in the neighborhood of $500,000,000 of which $140,000,000 is said to represent the cost of spoiled merchandise and of building - cleaning." This is all caused by the smoke dirt that descends in the United States at the rate of from 125 to 1,900 tons per square mile per year," and "making a sloping mountain estimated at 1,500 feet high."

Based upon the items listed above, the Mellon Institute reported that the annual loss from smoke in Pittsburgh amounted to approximately $10,000,000. New York estimates its smoke toll at $96,000,000 which represents a cost to the average New York family of $56 a year.

Samuel B. Flagg [10] estimates that the smoke tax in Chicago is equal to four-fifths of all the taxes levied in that city for municipal purposes.

The action of smoke upon the life of metals can readily be understood from Table II prepared by the Mellon Institute.

TABLE II

Length of Life of Metal	Smoky City Years	Smokeless City Years
Galvanized sheet iron	3 to 6	7 to 14
Galvanized sheet metal	3 to 4	5 to 10
Tin sheet iron	13 to 15	18 to 28
Tin sheet steel	6 to 10	10
Copper	10 to 20	No limit

The Mellon Institute has also estimated that enough sulphuric acid is annually produced from the coal burned in Pittsburgh to destroy 500,000 tons of limestone under proper conditions. Obermeyer says that "when smoke is prevalent virtually all kinds of stonework tend to disintegrate; only slate and granite are capable of resisting for any appreciable time.

"On growing things, smoke exerts a detrimental effect in three ways: (1) It blocks the pores, thus impeding transpiration; (2) It coats the leaf thus reducing transmission of sunlight; (3) It is likely to exert a poisonous effect directly on the plant or indirectly on the soil."

Economics of the Smoke Problem. We have already said that the annual bill for property damage caused by smoke amounts to $500,000,000 annually. We must not forget the cost of fuel wastage which must be added to this. The Holland Institute of Thermology of Holland, Michigan, estimates that this amounts to $200,000,000 annually, and is due largely to smoke and soot. Moreover, coal is not only burned so that only a small amount of its potential heat value is utilized, "but millions of dollars are being squandered yearly in basic materials for fertilizers, dyes, drugs, and a host of other adjuncts of the chemical industries" which can all be obtained from coal.

It is a very simple matter to realize that we are wasting staggering sums of money while we have passively tolerated the presence of smoke in our cities. Furthermore, the health of the American people is constantly being impaired, and this loss cannot be evaluated in terms of dollars.

Unquestionably, smoke as a result of our technological era is one of our greatest public enemies.

. . . . . .

Our forefathers as American pioneers, with their great determination laid the foundation for the development of this nation.

Certainly the group of pioneers that established the city of Salt Lake contributed their full share toward the ex-

pansion and development of our country. Without doubt they envisaged a beautiful city built in the picturesque valley of Great Salt Lake. Unquestionably, they pictured the inhabitants of this city as healthy and energetic individuals.

The posterity of these pioneers have surely constructed a beautiful city, but it is submerged in an atmosphere which is for most of the year heavily laden with smoke particles - a condition so detrimental to life and to property. Would Orson Pratt , if he were now to view this valley housing thousands of chimneys volumniously belching forth streams of smoke, express his feelings with "It is the grandest view I have ever seen"?

It is time to inquire: Shall Salt Lake City be known as the Pittsburgh of the Rockies? Shall its inhabitants continue to suffer with the many ill effects of the smoke which has been with them for many years? Not if the citizens of this community which is widely advertised as "The Center of Scenic America," will answer the challenge of smoke elimination with the vigor and determination characterized by the pioneers.

METHODS OF ELIMINATING SMOKE

The burning of any fuel causes combustion products to be formed. If the combustion is imperfect, that is, if there is a deficiency of oxygen in the combustion chamber, then minute solid particles - called soot - are produced. Samuel S. Wyer (11) writing for the Fuel-Power-Transportation Educational Foundation says that "soot is a mechanical mixture of fine particles of unburned carbon, tar, and ash, and frequently sulphur and other compounds." Visible solid material is responsible for the black color of the products of combustion which are then commonly termed smoke.

Concerning the combustion of coal, O. P. Hood (12) writes, "The black smoke which escapes when coal is burned, is due to incomplete combustion of the volatile matter of the coal. It is very difficult to produce black smoke in burning coals which are very low in volatile matter, such as anthracite."

Obviously then, in order to eliminate smoke as a result of burning bituminous or high volatile coal, there are two courses to follow. One is to supply by some means enough air or oxygen to completely burn the volatiles and the other is to remove and to recover the volatiles before the coal is burned.

There are several methods which have been devised with an eye toward the elimination of smoke. The purpose of the immediate paragraphs is to outline the salient features of each method as they are subsequently discussed.

Smoke Abatement. Smoke abatement has as its aim the education of the public, (1) to the best method of firing raw coal by hand without the evolution of smoke, (2) to the smokeless method of operating a mechanically fed furnace or boiler plant, and (3) to the many advantages of burning coal without smoke. To insure that the public puts this knowledge into practice, an observation tower is usually utilized to discover the chronic smoke-producers and then attempts are made to remedy the trouble so that no smoke is generated in the future. An essential agent in such a scheme is a city smoke ordinance which provides for a technically trained supervisor with assistants whose main function is to supervise the proper construction of new heating plants, and to impose fines upon "any person or persons, or corporation" for permitting the emission of dense smoke over a period of more than a specified number of minutes (usually six) in any one hour. Smoke is usually considered "dense" when it is of greater density than No. 3 of the Ringelmann smoke chart. The employees of the smoke abatement department of the city are appointed by and are responsible to the city officials.

The Use of Gaseous and Liquid Fuels. These fuels usually consist of blast-furnace gas, by-product coke-oven gas, and natural gas, and mineral oil, or petroleum. They are generally adapted for industrial and domestic use.

According to Gebhardt [13], "Gaseous fuels, on account of their simple molecular structure, can be burned readily and without smoke in any commercial apparatus from a boiler furnace

to a gas engine. Such fuels are in the ideal form, for perfect combustion, and permit of simple automatic control." This same authority gives the heating value per standard cubic foot of gaseous fuels as follows:

Natural gas	720 to 1700 B.T.U.
Blast-furnace gas	85 to 110 B.T.U.
By-product coke-oven gas	400 to 550 B.T.U.

However, Natural Gas does present some difficulties in burning. According to a bulletin (14) of the Committee of Ten-Coal and Heating Industries, "Natural Gas is relatively difficult to burn efficiently. It is a highly concentrated gas fuel with a high ignition temperature, requiring approximately one cubicfoot of air for each 100 B.T.U. of gas burned. Being so much lighter than air it does not mix readily and if sufficient turbulence is not provided to insure intimate mixture of the gas and air there is considerable loss through unburned fuel escaping up the flue."

The mineral oil used for heating is more commonly known as fuel oil and is derived from crude earth oil. In a broad sense, (15) "fuel oil includes all oils used for fuel purposes - kerosene, distillate, residuum and even crude oil. In market quotations and among oil burner men, however, fuel oil is the residual product after the gas oils, kerosene and distillates have been removed." Commercial standard grades of fuel oil have gravities (16) ranging from 14 to 40 degrees Baume and contain from 152,000 to 136,000 B.T.U.'s per gallon respectively.

Electricity. The province of electric heaters lies in the fact that by their use the heat can be automatically and uniformly maintained, and started or stopped instantaneously with-

out loss of energy. The elementary form of a heater is some form of resistance, such as coils of thin wire introduced into an electric circuit and surrounded with a substance of special form which will permit the conduction and radiation of heat.

Obviously, the utilization of electrical energy for heat does not in any manner involve the production of smoke.

Mechanical Stokers. Stokers are mechanically operated devices employed to feed solid fuels into the combustion chambers of industrial and domestic heating plants. They are designed to eliminate smoke by continuous feeding of the coal and uniform distillation of the volatile matter in the presence of sufficient oxygen. It is for this reason [17] "that mechanical stokers, as a class, are more effective in producing high combustion efficiency and in preventing smoke than any apparatus accompanied by intermittent firing."

Mechanical stokers may be classified under three general types, traveling chain grate, overfeed and underfeed. All three may be employed for industrial use, while the latter two are installed for domestic use.

Besides the reduction of smoke and increased burning efficiency, stokers effect a saving in attendance and a gain in the flexibility of operation.

Solid Smokeless Fuels. There are generally two types of solid fuels which do not give smoke upon combustion. It has already been mentioned that natural anthracite because of its relatively low volatile content, does actually burn without smoke. Likewise, artificial anthracite, produced by destructive distillation of bituminous coal to remove a large portion of

the volatiles, burns freely and with no smoke. Generally speaking, the latter fuel is produced in the form of the original coal lumps and also in agglutinated masses called briquettes.

The general advantages claimed for this processed fuel are that it burns freely, gives more efficiency than the raw, untreated coal, and burns smokelessly under ordinary operating conditions without the aid of mechanical equipment.

THE PROBLEM OF ELIMINATING THE SMOKE IN SALT LAKE CITY

In 1930 there were 140,267 persons living within the boundaries of Salt Lake City. Approximately 700,000 tons of bituminous Utah coal is burned annually in 29,000 heating plants. A survey [18] has indicated that 400,000 tons are annually consumed for industrial purposes, while the remaining 300,000 tons are burned for domestic uses.

Facts about the Polluted Atmosphere. Let us first consider what effect the burning of raw coal has had on the pollution of the surrounding atmosphere.

From a study [19] of Salt Lake City's smoke problem made by the Federal Government in 1920, it was found that "there is a very marked seasonal variation in the character and amount of atmospheric impurities in Salt Lake City." The authors of this work continue as follows:

> "With the beginning of the heating season the amount of coal smoke begins to increase, until in December and January the city is often hidden in a pall of fog and smoke so dense that it is impossible to distinguish objects 100 yards away. This smoke cloud is seldom pure soot, but is usually mixed with water vapor. The humidity in winter is high, and smoke particles act as nuclei for the condensation of water vapor. Fogs therefore occur more frequently than if the atmosphere contained no foreign particles. Such fogs are dissipated with difficulty by the sun and may exist without evaporation for a long time, although the humidity of the atmosphere is far below saturation."

"In the winter, when the smoke nuisance is at its height, the atmosphere is remarkably free from dust of non-fuel origin but contains relatively large amounts of soot and ash from coal fires. Due to its color and fine state of division, such material is a much greater nuisance, weight for weight, than the coarser and heavier industrial and other dust."

. . . . . .

"In the growing season from April through October the impurities are principally dust of non-fuel origin."

Table III, as taken from the report of the study cited above, shows in brief the results of atmospheric analyses for Salt Lake City.

TABLE III

COMPOSITION OF THE AIR OF SALT LAKE CITY
DURING THE HEATING SEASON OF 1919-1920

Milligrams per Cubic Meter				
Chlorine	Ammonia	Sulphuric Acid	Nitrous Acid	Solids
0.002 to 0.004	0.001 to 0.08	less than 0.1	0.0018 to 0.0322	0.1 to 2.5

The average amount of carbon dioxide present is but 35 parts per million higher than that present in the pure country air. Therefore "carbon dioxide is a negligible factor in the pollution of Salt Lake City atmosphere."

We are also told that "chlorine is present in very minute amounts and is possibly carried as spray from Great Salt Lake." Sulphur acids and ammonia are likewise present in small quantities,

so that "none of these impurities is present in harmful amounts."

The average figures for the soot fall in the center of the city during the period from September 1, 1919 to May 1, 1920 showed that the total solids descended at the rate of 349 tons per square mile per annum of which 122 tons or 35 per cent was combustible matter.

TABLE IV

COAL CONSUMPTION AND SOOT FALL
AT REPRESENTATIVE CITIES-1920

	Coal Consumption, tons per annum	Soot fall, tons per square mile per annum	Soot fall, tons per square mile per annum per million tons of coal
London	16,000,000	58-426	3.62-26.6
Leeds	1,500,000	25-539	16.7 -360
Glasgow	3,250,000	1,325	408
Hamburg	3,000,000	345-690	115-230
Pittsburgh		595-1,807	
Salt Lake	510,000	15-980	39.4-1920

Table IV above is condensed from a similar table in the report just referred to. From this table, it is concluded that "in comparison with its coal consumption, Salt Lake shows the highest rate of soot fall of any city in the table, even if the smaller area is considered."

As far as the writer knows, these data pertaining to Salt Lake are the most authentic and recent facts available. Even though the work was done fourteen years ago, it is reasonable to believe that the conditions today are quite similar to those of

1920, since we still have the smoke problem with us in spite of the fact that many stokers, oil and natural gas installations have been made. It must also be remembered that since 1920, the annual coal consumption of Salt Lake has increased approximately 40 per-cent!

Outstanding Facts Concerning the Formation of Salt Lake City's Smoke Screen. Salt Lake City is bounded on the east and north by the Wasatch Mountains and on the southwest by the Oquirrh Mountains; it occupies, therefore, a peculiarly sheltered position and this has a marked effect on the wind velocity and consequently the movement of the smoke. In the early morning at the time of maximum smoke production, the atmospheric temperature and velocity of the wind are at a minimum. As a result of these natural conditions there is created a most unfavorable combination of factors which are responsible for the very serious smoke problem.

The writer and others on many occasions during the relatively mild winter months of 1933-34, noted the manner of formation of the smoke cloud from a high point on the mountains to the north of the city. The observations were usually taken from 6 a.m. to 9 a.m., and because of the rapidly changing atmospheric conditions, data were obtained every ten or fifteen minutes. It was noted that the formation of the smoke cloud was seldom exactly duplicated, but certain general characteristics were discovered and are herein presented.

At 6 a.m., while it was yet dark, the lights of the city and the surrounding towns could be clearly seen. When a slight breeze had been blowing, the city's lights presented a brilliant spectacle.

By 6:15 the lights from south Salt Lake to Murray were beginning to get dimmer due to a smoke haze which moved in from the south. This "smoke-wave" now augmented by thousands of cottage chimneys, rapidly spread north over the city so that by 6:30 the lights of the Sugarhouse business section and the adjoining residential district were either very dim or were entirely obscured as far north as 9th South, which is approximately one mile and a half north of Sugarhouse in the southeast section of the city. The north eastern portion of the smoke cloud was then at about 7th East, while the western margin was somewhere beyond the farthest city light in the west part of the city.

The eastern mountains more faintly visible by 7 a.m., while the smoke cloud had then advanced until the only lights that were visible were those which were nearby on the north bench and some adjacent to the University of Utah, also the airplane beacon located on the side of the Wasatch Mountains to the east was visible.

After fifteen minutes more had elapsed, the city's smoke began to be visible and the landmarks could be faintly distinguished. By 7:30 the sky was bright and the smoke cloud had now covered the city like a huge blanket extending from Murray on the south to the Capitol Building on the north; and from the salt flats near Great Salt Lake in the west beyond the University in the east.

Thousands of streams of smoke could be seen drifting from the chimneys on the east bench toward the city. At times, the Oquirrh Mountains were hardly discernable, being behind the deep smoke blanket covering the city.

The low velocity of the prevailing wind (frequently about six miles per hour), provides little opportunity for removal of the smoke, even though aided by slow dilution in the atmosphere above the city. The descending air currents from nearby canyons cause the smoke to become deeper over the business section, until it reaches a height of at least 200 feet. Frequently the dome of the State Capitol is submerged in the deep smoke blanket.

We see therefore, that even during an exceptionally mild winter, the smoke produced presents a distinct nuisance. To further illustrate this, Figures I and 2 are presented to show the formation characteristics as well as the intensity of the smoke cloud.

The Relation of Methods of Eliminating Smoke to Salt Lake City. The general methods of eliminating smoke have been previously described. Our purpose now will be to assume these methods as applied to the situation in Salt Lake. We will particularly note whether these methods offer possibilites of mitigating

Fig. 1. View From the U. S. Veteran's Hospital Looking South over Salt Lake City, Utah

7:30 A. M. Jan. 31, 1934

Fig. 2. View of the Utah State Capitol Building

7:30 A. M. February 2, 1934.

or of completely eliminating the smoke cloud.

Smoke-abatement in Salt Lake has been attempted over a period of years beginning in 1890, when efforts were made to control the burning of soft coal in heating and industrial plants. It is a matter of record that some six active smoke-abatement campaigns were born and buried between 1890 and 1919.

During the heating season of 1919 to 1920, a survey and an analysis of the smoke problem were made by the United States Bureau of Mines in cooperation with the city and the State School of Mines and Engineering. This was a separate study from the investigation then in progress by the petroleum division of the Federal Government and the State of Utah to determine the oil, gas and smokeless fuels possibilities of Utah's enormous bodies of carbonaceous materials.

Following this, a Department of Smoke Inspection and Abatement was organized by the city in 1921. An ordinance patterned after the recommendations made in the government report of the previous year, was put into effect and has been operating since that time. A total of six minutes of smoke in any one hour with a minimum density of No. 3 of the Ringleman Chart, was defined as a violation of the ordinance. The well known requirements of draft, size of combustion chamber, stoking equipment, etc., which pertained to the installation of new equipment were incorporated in the ordinance.

An observation point in a tall building was utilized to apprehend the offenders of the law.

The first work was centered on the large industrial and heating plants as the worst offenders. Many drastic changes were made and they principally involved the installation of stokers and the enlargement of the volume of combustion chambers.

The design of the combustion equipment of railroad locomotives was successfully modified. Many smoke-prevention devices were suggested, and through the cooperation of the railroads, there was not one engine operating within the city limits in 1930 that was not fully equipped to operate smokelessly.

The home owners were asked to start fires by kindling from the top of the raw coal charge and were also instructed to place green coal on a section of the grate entirely free of hot coals in order to prevent the too-rapid distillation of the volatile matter. It was by these methods that some slight smoke reduction from domestic heating plants was obtained.

In April 1930, after nine years of smoke-abatement work in Salt Lake City, Austin Gudmundsen [18] writes in conclusion, (1) that the smoke from large industrial and heating plants had been reduced at least 90 per cent, so that it may be safely stated that at least 85 percent of the smoke produced now comes from city residences, (2) that for a smoke-

abatement campaign to be successful, it must be continuous, (3) that after ten years of activity in smoke-abatement, and in spite of the substantial reduction effected, Salt Lake City still has a serious smoke problem, (4) that permanent relief will depend on complete elimination of residence smoke, and (5) that so long as any appreciable amount of smoke is made in the residence section, a smoke cloud will be formed.

From these conclusions, it is evident that smoke-abatement measures in Salt Lake have been of considerable value in reducing the smoke caused by industrial plants, but has been of little help, if any, in alleviating the residential smoke. Gudmundsen explains that smoke from residential furnaces is formed because of the lack of proper introduction of secondary air over the fuel bed, and says that "this is probably the most serious defect in domestic furnaces. Because of the poor draft available enough air simply can not be drawn through the small slots usually provided; and with the door partly open, the air goes into the furnace too high up and with such slow velocity that poor mixing always results. As a consequence, only fair results are possible at best. Furthermore, few residence-furnace operators are willing to keep the door ajar; it is evident, even to them, that poor economy results, and again, it requires running up and down into the furnace room to close the door when the volatile matter has been burned." From the above, it can be concluded that the personal factor

must be coped with, but it must be understood that for smokeless combustion, proper fuel, correct furnace volume, and proper air admixture must be obtainable.

In addition to the smoking furnaces, there are almost as many coal fired room heaters, about three thousand coal cook stoves and many more fireplaces which are the sole contributors to the production of 85 percent of the city's smoke.

Even though it is known that proper methods of starting and maintaining a domestic coal fire do tend to reduce the smoke to a measureable degree, it can not be disputed that to do this requires a great deal of information, supervision and resourcefulness on the part of the home owner. These are human propensities which in this instance cannot be relied upon; otherwise, our smoke problem by this time would have been resolved into no problem at all. It is also a known fact that for the continuous smokeless operation of all stokers now being used, the human element enters into the picture and to such an extent that in many cases dense smoke is produced because of careless control and maintenance of this type of firing equipment.

In the opinion of the writer, smoke-abatement measures as herein described, have now had the greatest attainable effect upon the elimination of the smoke from Salt Lake City. The industrial smoke which was, in 1921, the easiest to remedy, has now been reduced to a small fraction of its former intensity; and the elimination of the smoke from domestic heating plants has admittedly come to a standstill because of the proven ineffectiveness of present smoke-abatement measures.

However, the City Smoke Inspection and Abatement Department still has necessary instructional and enforcement functions to perform. It is very easy to see that should this department be abandoned at the present time, smoke production would undoubtedly be much more abusive than it is now. Therefore, whole-hearted continuation of the smoke tower observations, inspection of present industrial heating plants, and supervision of the selection and installation of new coal-burning equipment of all kinds are necessary public duties of the department and should be encouraged.

Notwithstanding this, it must be realized that smoke-abatement work is really only a palliative measure and that other means must be devised to remove the harmful smoke nuisance and to insure prevention of its recurrence from the residential heating plants.

Before further discussion of this subject can properly be made, it is first necessary to obtain and analyze the most dependable data concerning the types and numbers of heating plants within the city.

No complete data are as yet available for this purpose, but the figures presented in Tables V, VI and VII below are approximate figures which are used by the city Engineering Department. They were given to the writer by Mr. J. Billeter, Chief Engineer of Smoke Abatement, Salt Lake City Corporation.

TABLE V

NUMBER OF HEATING PLANTS IN SALT LAKE CITY

Furnaces	15,150
Water and Steam Plants	3,000
Heating Stoves	11,150
Total	29,300

TABLE VI

METHODS OF FIRING THE HEATING PLANTS

Gas	3,500
Stokers	2,000
Oil	300
Hand fired	23,500
Coke	(no figures)
Total	29,300

TABLE VII

NUMBER AND GENERAL TYPES OF COOK STOVES

Electric	10,600
Gas	15,700
Coal	3,000
Total	29,300

In commenting upon these tables, Mr. Billeter expressed the opinion that the figures for the furnaces are too high, and that those for the heating stoves are too low.

From these tables it can be clearly seen that 85 percent of the smoke comes from the 23,500 hand fired heating plants comprising 11,150 heating stoves, 3,000 coal cook

stoves, and 12,350 coal fired furnaces and water and steam plants.

This serves to emphasize the fact which has been pointed out before, that any method of complete elimination of the city's smoke must necessarily concern itself with the domestic heating plant.

Mr. J. D. Roberts, Vice-President and General Manager of the Utah Gas and Coke Company, in a discussion of a paper (20) presented in 1929 on Salt Lake City's Fuel and Smoke Problem said,

> "In reality the remedy (for the deplorable smoke nuisance and fuel problem) is at hand in the form of natural gas, which will be turned into the mains of the Utah Gas and Coke Company early in September. This fuel, which has cleared the sky lines of many cities throughout the Southwest and has made them more pleasant places in which to live, will be available to practically all of the inhabitants of Salt Lake City, Ogden, and to those towns lying between Salt Lake City and Ogden and west and south of Salt Lake City, at a price equal to the present market price of coal. ---- Salt Lake City is not watching an experiment. It is merely awaiting a certainty."

It is very evident to Utah citizens that after four years service from the imported natural gas, we have the smoke cloud which still assumes the same alarming proportions year in and year out.

Certainly no one can deny that the bringing of natural gas into Salt Lake has failed to bring the promised relief. This has been due in part to the present

high prices of gas and gas burning equipment, so that the people in general have not been financially able to make use of the smokeless combustion characteristics of natural gas. Furthermore, many Utah citizens and some public officials have refused to use the imported gas as a detriment to Utah's present coal industry. Its use would obviously become a barrier to the smokeless fuel and coal-products industry based on the Federal Government and the State of Utah's extensive researches.

Because of the present high cost and probable higher future cost, fuel oil has not found widespread use. Generally speaking the burning of oil in Salt Lake residences is more expensive than the use of natural gas, and is a far less popular fuel. Also it is recognized that the atmospheric pollution caused by imperfect burning of oil is more damaging to property than the soot from coal.

At the present time the rates for electricity are so high, that no one is proposing that this form of energy be used for general heating purposes. The local power company is not advocating this and is not offering heating equipment for sale. Electricity for house heating would have to sell for .3 to .75 cents per kilowatt hour to equal heating costs of coal at present domestic prices.

Therefore we can see that the use of electricity as a method for keeping residences warm without the production of smoke, is not now practicable from an economical point

of view.

A rival of natural gas is found in the stokers adapted for domestic installations. The chief advantage of the stoker firing over the hand firing of raw coal lies in the automatic features of the former method. In this manner, the burning of coal without the attendant work of hand firing, becomes a competitor of the automatic features of gas burning equipment, both being equipped with automatic temperature regulating thermostats.

For some time it has been known that better conditions are created for the combustion of high volatile coal and greater overall efficiency of the heating plant is obtained with stokers than by average hand-firing of furnaces. It has also been shown that by this method, the combustion process takes place with practically no evolution of smoke during most of the operating period. Otto Duke (21) reports that stoker fired furnaces can reasonably be ten per cent more efficient than the hand fired plants.

The problem of "fly ash" carried out into the atmosphere from mechanically fed furnaces seems to be a serious one. Duke's tests (these tests are those which were done under a Government C.W.A. project during 1934) show that on the average there is 0.06 lb. of fly ash per 100 lb. of coal. If, as an example, one-half of the annual coal consumption or 350,000 tons were burned with stokers, 180 tons

of fly ash would then pollute the air.

Recent observations from the city's smoke tower show that without question, the greatest percentage of violations of the smoke ordinance are from heating plants which are stoker operated. This is true mainly because of the fact that the attendant is (1) either starting the fire, (2) or is feeding the coal into the combustion chamber beyond its capacity to burn the volatile of the coal without smoke, or (3) is cleaning the fire.

Added to the personal element in the smokeless operation of stokers is the fact that the stoker can not be applied to the 11,000 homes now heated with stoves in the city.

According to Dean R. B. Ketchum (22), Dean of the School of Mines and Engineering, University of Utah, the 12,350 hand fired furnaces including the water and steam plants might be provided with stokers at an average cost of say $250 each, or a total of $3,000,000 but without a smokeless fuel, there is no practical way to eliminate smoke from the 11,000 hand fired stoves, except to equip them with gas burning appliances at say $100 each, or a total of $1,100,000. ---- Since the above shows that the smoke elimination involves a cost to Salt Lake City residences of $4,300,000 to buy new equipment for present fuels, and in view of the fact that statistics show that the yearly cost of smoke damage to Salt Lake City is from $10 to $25 per capita, or from $1,400,000 to $3,500,000

annually, to say nothing of the health considerations, it is evident that we are dealing with a large economic problem worthy of our best endeavors."

CONCLUSIONS PERTAINING TO THE COMPLETE ELIMINATION OF SMOKE FROM SALT LAKE CITY

1. Smoke-abatement work is not an adequate solution to the problem because the typical methods employed can not eliminate the smoke produced by the residence heating plants. The fault lies in the type of fuel used and the improper design of the burning equipment employed.

2. Gas, oil and stokers all provide means of reducing the smoke, but can never completely eliminate it because added expense is always entailed to the house owner, and thereby their widespread use is precluded. Gudmundsen [18] has said that "even if 50 per cent of the domestic coal burning equipment were eliminated, conditions would still be undesirable. It may be that the use of natural gas, stokers and such smokeless fuels as are now available, coupled with an intensive campaign in the residential section, as much as 60 per cent of the remaining smoke can be eliminated. But this is not enough. The remaining 40 per cent will still comprise a distinct nuisance."

3. The use of electricity for domestic heating is out of the question under present conditions, simply because the rates for electrical energy are too high to compete with other methods of heating.

4. It has already been pointed out that smoke caused

by the combustion of Utah coal might be eliminated in two ways: (1) by the proper design of the combustion chambers of all types of heating equipment so as to secure thorough mixing of the air and the distilled volatile vapors from the coal, thereby permitting the burning of the volatiles in the furnace without allowing their escape into the atmosphere as visible smoke, and (2) by removing enough of this valuable, smoke-producing volatile matter (oil) before the coal is burned, whereby the air supplied by the common coal burning appliances will be sufficient to insure smokeless combustion.

The first method is the intent of modern stoker installations, and has proven to be of considerable value in smoke reduction. It has been well demonstrated, however, that stokers do not always provide smokeless combustion.

5. Metallurgical coke manufactured at Ironton, Utah has been used with some success in furnaces as a domestic heating fuel. However, experience has shown that it is hard to ignite, and that if precautions are not taken, it will either burn out the grates in the fire box or the fire will go out. Moreover it is an expensive fuel and sells from $7.00 to $9.00 a ton on the retail market. This type of coke has not enjoyed widespread popularity among the home owners of Salt Lake City, although its use has been popularized in some eastern cities for furnace fuel.

6. In view of the above facts, it is obvious that

some new method of heating must of necessity be devised in our cities, that is, if our smoke problem is going to be solved in the near future. The solution lies in the application of the second method given under item 4 above. What is really needed is a new fuel containing a percentage of volatile matter low enough so that no smoke is produced upon combustion in our present equipment, and yet high enough so that it gives longer flame in burning, and, of greatest importance, it must be an active form of carbon which is easily ignited. Furthermore, the fuel must be capable of burning in any common heating device unaided by mechanical auxilaries. And finally, the fuel must be sold at a low enough price so that everyone can afford to buy it. A widespread market will then be assured, and as a result, the smoke cloud can be completely erased from the horizon of Salt Lake City forever!

The following subject matter of this work is chiefly concerned with a discussion of the manner in which this new type of smokeless fuel can be made, and also with its burning characteristics.

The medium for the production of smokeless fuel is generally known as "Low-Temperature Carbonization", the details of which will be subsequently discussed.

COAL CARBONIZATION

General Features. When raw coal, as it comes from the earth, is heated in the absence of air to prevent combustion, the process performed is known as the carbonization or destructive distillation of coal. The heat supplied causes the breaking down of the complex carbonaceous ingredients of the coal into gases, liquids, and solids, with the simultaneous vaporization of the liquid products. The volatilized matter thus consists of gases and vapors principally of hydrocarbons, tar acids and water. A variable solid carbon residue is left as a result of the carbonization treatment, and this may be of the graphitic or the more chemically active type of carbon with varying amounts of residual gas-producing volatiles, also its density and structure may be controlled. The terms "high-temperature" carbonization and "low-temperature" carbonization are used to describe the two broad classes, or types of coal treatments, that technological developments in coal distillation (pyrolysis) have been most extensively applied thus far.

High-temperature Carbonization. This class of coal-processing has been commercially used since the completion of the Clinton furnace of Graff, Bennet and Company, at Pittsburgh, in 1859.[23] At this time, the successful use of the carbon residue or coke, as a blast-furnace fuel was satisfactorily demonstrated.

The primary object of this procedure is to make a strong metallurgical coke of high carbon content for use in the smelting of iron ores. This end has been progressively attained, from the earliest methods of coking in mounds or piles to the modern by-product oven. A local example of the process is the Columbia Steel Corporation's plant using Koppers type by-product coke ovens at Ironton, near Provo, Utah. A coking or fusing type of coal is used to produce coke for the company's iron blast furnace plant. The ovens are capable of producing from each ton of coal about $\frac{2}{3}$ ton of coke, 15,000 cubic feet of gas, 11-12 gallons of coal tar, $3\frac{1}{2}$ gallons of benzol and several pounds of ammonium sulphate.

Generally speaking, the coal is carbonized at temperatures ranging from 900° to 1200° C. (1652° to 2192° F.) producing a coke with very low volatile content (about 2 per cent) which is of a graphitic type and is correspondingly difficult to ignite.

Low-temperature Carbonization. As the title indicates, low-temperature carbonization is carried on at relatively low temperatures, which may range from 360° to 750° C (680° to 1382° F.). The fundamental reason for use of lower temperatures, as will be explained later, is to prevent secondary decomposition of the distilled vapors, so that the vaporized constituents of the coal will have certain valuable characteristics different from the vapors of the high-temperature process. In addition to this, the carbon residue which is generally called "semi-coke" is not graphitic so that it ignites and burns more readily than the high-temperature cokes.

High and Low-Temperature Carbonization Contrasted. In discussing this subject, Gentry [24] has compiled a table (Table VIII below) comparing the two types of carbonization, which is based on an eastern coal having 35 per cent volatile matter, 7 per cent ash; and 58 per cent fixed carbon.

TABLE VIII

GENERAL COMPARISON OF HIGH AND LOW-TEMPERATURE PRODUCTS

Product	Yield per net ton	
	High Temperature	Low Temperature
Gas (cubic feet)	11,000	5,100
B.T.U. per cubic foot	540	825
Tar (gallons)	10	20
Light Oil (gallons)	2.5	3
Ammonium Sulphate (pounds)	22	14
Coke (pounds)	1,500	1,500

It must be understood that these are general figures in no wise applicable to Utah's coals, and only serve to indicate the directions in which the yields from the two processes differ.

We see that low-temperature carbonization produces a smaller amount of gas but with a higher heating value, that it produces considerable more liquid hydrocarbons, less ammonium sulphate, and that the yields of coke are about equal.

LOW-TEMPERATURE CARBONIZATION

Introduction. In order to completely understand what takes place when coal undergoes heat treatment, it is necessary to be familiar with the manner in which coal was originally formed, and the salient facts pertaining thereto. For this reason, coal and other earth hydrocarbons such as oil and natural gas, are described in some detail in the appendix of this thesis.

There are four general constituents of coal which have been called: (1) the carbon residuum, (2) the humus bodies, (3) the resinous bodies, and (4) the hydrocarbons. Upon distillation, the last three undergo thermal decomposition with the formation of solid, liquid, and gaseous products, as shown by Table IX prepared by Lewes (25), while the

TABLE IX

THE CONSTITUENTS OF COAL AND THEIR DECOMPOSITION PRODUCTS

Constituents	Decomposition Products		
	Solid	Liquid	Gaseous
Humus bodies	Carbon	Water Thin tar	Carbon oxides Methane
Resinous bodies	Carbon Pitch	Water Rich tar	Carbon oxides Ethylene Unsaturated hydrocarbons
Hydrocarbons	Carbon Pitch	Heavy tar	Methane Ethane Homologues
Carbon residuum	Unaffected by heat		

first contains principally carbon and ash.

The resinous bodies, which are soft in structure and dark brown in color, appear in the coal as slender rods. Many of the volatile hydrocarbons of bituminous coals are the decomposition products of the resinous and humus constituents of coal. Proximate analyses, according to Table X [24] show that the resin differs from the humus in that

TABLE X

PROXIMATE ANALYSES OF RESIN AND HUMUS IN COAL

Constituent	Resin per cent	Humus per cent
Moisture	0.68-0.70	2.57-2.62
Volatile Matter	98.00-97.94	51.68-51.74
Fixed Carbon	0.80-0.82	44.73-44.60
Ash	0.52-0.54	1.02-1.04

its volatile matter is higher and the fixed carbon considerably lower.

The resinous compounds and the hydrocarbons are the constituents of coal which cause the formation of most of the smoke due to incomplete combustion in the burning of raw coal. These smoke-producing, but otherwise valuable products, are removed by carbonization.

Fundamentals of Coal Distillation. According to S. W. Parr [25], while describing data obtained with particular coals and carbonizing apparatus, says there are two distinct

carbonization zones: one below 450° to 500° C (900° F), and one above. He says, "Carbonizations at temperatures below this line are distinctive in behavior and in products, and the attending conditions are fixed and definite, and indicate in what manner and with what material the procedure may be undertaken. Similarly, carbonizations at temperatures above this line are distinctive in behavior and products, and the attending conditions yield results that are fixed and definite from both physical and chemical standpoints."

"In the first or lower zone, the first one hundred degrees of temperature are required to drive off the moisture, and until this work is completed the temperature does not rise above 100° C."

Parr's statement, of course, applies to any method by which coal substance is heated through the range of temperatures. His discussion pertains, however, to processes requiring some 15 hours for distillation, whereas the time required in the process used by the writer in this present study averages approximately two hours depending upon the coal used. What is said here concerning the rate of heat transfer as brought out by the present studies and in the fundamental work of Parr, is in order that the reader will have a basic understanding of what takes place when coal is carbonized.

The yield and character of products, also the fundamentals of destructive distillation, are convincingly shown in the researches and data obtained by L. C. Karrick in U. S.

Bureau of Mines Bulletin 249 and in the American Chemical Society Monograph No. 25.

Parr continues further in describing the thermal changes taking place in an externally heated mass of (fusible) coking coal: "We find that the curves from any standard process show an indisposition to rise until after 200° C. has been passed. If no influence other than simple heat conductivity were operating after 100° C. had been reached, then these curves from and at 100° C. up to say, 500° C. would be straight lines. Some influence is operative which tends to depress these lines and keep them below 200° C."

"In explaining these phenomenon we are greatly assisted by the following information which has been obtained in recent years from various sources."

"Below 300° C. the coal is still in the granular or non-pasty stage. Below the pasty stage there has been no decomposition of a sort to deliver hydrocarbon vapors. There is, however, a rearrangement or condensation of organic constituents carrying hydroxyl and carboxyl groups of such a nature as to split off carbon dioxide and water."

"The resultant heat effect of these reactions over this range of temperature is endothermic and is substantially the same as the absorption of heat that occurs below 100° C. in the vaporization of the free water content of the coal."

Parr found that the faster the heat was applied, the

shorter was the period of the endothermic reaction. The next reaction taking place between, say from 300° C. when the coal assumes a pasty stage, and 500° C., is exothermic and the products are hydrocarbons instead of the oxides of carbon.

Parr goes on to say: "This exothermic reaction is not only a function of the time required for attaining these critical temperatures (of 200° and 300° C.), but it is of decidedly more pronounced and positive character when it follows a quick accession of heat in the lower ranges, and is far less pronounced - in fact, almost annulled - where the accession of heat over the endothermic range is unduly prolonged."

"Indeed, the zone below 300° C. would be very properly designated as the conditioning stage for establishing a certain chemical status, from which very profound and fundamental differences in the behavior occur above the critical temperature."

Products of the Lower Zone

Tars. "The yield of tars is from two and one-half to three times as great as the yield from the high temperature process using the same coal. This is because there is very little secondary decomposition following the primary decomposition of the original substance undergoing carbonization. It is possible, of course, that some of the waxes or fossil resins are volatilized with little or no decomposition, but for the most part the condensable material is the primary decomposition product resulting from the

breaking down of the lignose type of organic substance which has descended by geological processes from the original plant material. In these tars the aliphatic series of hydrocarbons (such as methane, ethane, prapane, butane, etc.) predominates, so that the product is more like petroleum than tar. This material lends itself to cracking processes under specific types of control for the production of motor spirit, lubricating, fuel, or Diesel oil, or hydrogen and carbon black."

Gas. "The yield of gas is small owing to the small amount of secondary decomposition taking place in the tar. The range in volume is from 3000 to 5000 cubic feet per ton of coal carbonized. The gas is of high heating value and may average as high as 3½ or 4 million B.T.U. per ton as compared with 5½ to 6 million in the case of gas from standard processes (high-temperature carbonization)."

Solid Residue. "This is a char or semi-coke. It is high in volatile matter, averaging from 10 to 15 per cent."

Parr continues by explaining the difficulties encountered in discharging the semi-

coke from the retorts because of the swelling and sticking of the charge. It is well to note here that practically all coals of the Rocky Mountain area do not give trouble due to swelling, and that not one coal which was investigated adhered to the side of the retort.

In the upper zone of low-temperature carbonization, which Parr defines as from 500° to 750° C. (932° to 1382° F.), aliphatic hydrocarbons are still evolved up to 700° C. while hydrogen and ammonia are generated rapidly above 700° C. These facts were proven by Burgess and Wheeler [27] in 1910.

Parr considers that 750° C. is the upper limit of low-temperature carbonization. This is based on his studies of the ignition temperatures of the coke produced at various temperatures. He found that the higher the distilling temperature the higher was the ignition temperature of the coke, and that the relationship between the two was directly proportional. By studying this effect caused by both high and low-temperature distillation, he found that at 750° C., the ignition point was the same for the coke produced from the same coal by the two processes. This temperature was approximately 230° C.

Parr has attached special significance to this feature and explains his reasons briefly as follows:

1. "Coal carbonized at this temperature has less than 5 per cent of volatile matter, showing that decomposition processes within the coal substance are substantially complete."

2. "The gas yield, measured in terms of heat units, is substantially all that is available at any temperature. At higher temperatures the volume of gas may be greater, but the heat value per cubic foot will be less."

3. "The tars, not having been subjected to such violent secondary decomposition, are larger in amount, more uniform in composition, and of greater value, owing to the higher percentages of the active principles, the creosote oils, required in wood preservation."

Definition of Low-Temperature Carbonization. From the above discussion, an understandable definition can now be formulated. Gentry [24] says, "By way of a scientific definition, low-temperature carbonization is taken to mean the destructive distillation of coal at or below the cracking temperature of the hydrocarbons in primary tar. This temperature is, of course, a function of the physical conditions of retorting (which depend upon the pressures used). It will vary in practice with the quality of the coal and the economic

balance in grade of products that is determined by local conditions. For the most part, however, under atmospheric pressure and for average coals, 750° C. may be taken as the upper limit of low-temperature carbonization."

Such a definition is not applicable, however, in the light of data obtained in the writer's researches. It has been determined that coal begins slowly to yield oil vapors at 360° C. (680° F.) and that rapid evolution of vapors takes place at 425° C. (797° F.). Also many coal distillations were made at 650° C. (1202° F.) from which true low-temperature coal products were obtained. All of these temperatures are above the temperature at which the primary hydrocarbons or bitumens formed in coal begin to crack, and it is known that oils in the vapor phase will crack rapidly at 1200° F.

We know that the element of time is important in measuring the amount of cracking taking place at any of the temperatures mentioned. Consequently the writer believes that low-temperature carbonization should be defined necessarily as a "condition" and not as a "temperature range" of destructive distillation, - wherein a minimum of secondary decomposition of the oil vapors takes place, a relatively low yield of high B.T.U. gas is evolved, and the residue is an active form of carbon.

PROCESSES FOR LOW-TEMPERATURE CARBONIZATION

Historical. Recent interest in low-temperature carbonization of coal has been promulgated during the past 32 years. The most prominent contributor in this field is Prof. S. W. Parr in the United States, and Lander, Parker and Illingworth in England. Records show that approximately 250 processes have received considerable development in this relatively short period for the low-temperature distillation of coal and allied carbonaceous substances.

Fieldner [28] states that "there was no general interest in the subject until the World War focused the attention of England and the European powers on their lack of petroleum and their need for home sources of liquid fuels. .... This interest increased progressively in the 10 years after the war, due partly to the fear that gasoline from petroleum would not be able to keep pace with the mounting needs of the fast-multiplying numbers of automobiles and partly to the tremendous industrial expansion which sought to capitalize without delay every possible new application of the results of scientific research. The climax was reached about 1928, when, at the Second International Conference on Bituminous Coal, at Pittsburgh, more papers were read on low-temperature carbonization than on any other subject."

The most recent developments in the art of low-temperature carbonization have now been cited. However it is known that the production of oil from coal was not an uncommon thing many years ago, in this country as well as in England, Scotland and Germany.

Ashley [29] says, "The use of coal for the production of oil is not recent, it having been employed for the purpose as early as 1760. In Lewis's Materia Medica, published in that year, mention is made of oils distilled from black bituminous shales for medical purposes. Even earlier than that, in 1694, patents were issued to Eele, Hancock, and Portlock for making pitch, tar, and oyle out of a kind of stone. In 1781 the Earl of Dundowald distilled oil from coal, and others distilled oils and tars from bituminous schists, so that at an early date these oils, somewhat purified, were used for burning in lamps and for lubricating machinery.

"Abraham Gesner claims to have been the first to manufacture oil from coal in the United States, and in 1846 exhibited the use of his oil in lamps".

In 1860, when the first real discovery of petroleum occurred, there were 55 coal-oil plants operating in the United States, the largest having a distilling capacity of 6,000 barrels of oil per day. Kerosene (coal-oil), light lubricants, greases, and wax were the principal refined products, gasoline having no market value at the time. Most of the plants were in Pennsylvania, Kentucky,

and West Virginia, although one large coal-oil plant was in Boston.

Methods of Heating. The various processes which have been proposed, fall into two classes, namely, (1) externally heated retorts in which the coal is carbonized by heat supplied through the walls of the retort wherein the products of distillation are prevented from mixing with combustion gases, and (2) internally heated retorts in which the coal to be carbonized is heated by direct contact with hot gases or superheated steam passed through the retort in intimate contact with the charge.

Carbonization Systems. Carbonization can be carried on by the batch or intermittent system, in which case the coal is charged into an empty retort and remains there until the distillation is completed, whereupon the semi-coke or smokeless fuel is discharged at one time. The other system carbonizes the coal continuously and the discharging is either continuous or in small increments.

Retorts [30] can be classified as follows: (1) oven types, usually of rectangular shape, as the by-product oven; (2) vertical shaft types, as the vertical gas retorts or the Scottish oil-shale retort; and (3) rotating-cylinder types, vertical, horizontal, or inclined, similar to revolving driers or cement kilns; the cylinder type may also be stationary and have a revolving internal stirrer.

Table XI by Fieldner [29] gives an outline of the various retorting methods.

TABLE XI

CLASSIFICATION OF LOW-TEMPERATURE

CARBONIZATION SYSTEMS

A. Externally heated retorts - coal in thin layers, not stirred.

1. Vertical layers of coal in narrow retorts.
2. Horizontal thin layers of coal.

B. Externally heated retorts - coal stirred in contact with heated surfaces.

1. Vertical retorts.
2. Horizontal retorts.
   (a) Stationary retorts with internal stirrers.
   (b) Rotating cylinders.
3. Retorts with coal stirred on a flat heated surface.

C. Internally heated retorts - coal in direct contact with hot gases or liquids.

1. Hot gases generated by air or air and steam blown into the retort.
   (a) Coal charged in lumps or briquetts.
   (b) Coal charged in pulverized form.
   (c) Complete gasification.

2. Hot gases or vapors generated outside the retort.
   (a) Combustion products.
   (b) Producer gas.
   (c) Water gas.
   (d) Coal gas.
   (e) Superheated steam.
   (f) Combinations of the foregoing.

3. Melted lead in contact with coal.

D. Two-stage carbonization to control the sticking properties of the coal.

In the succeeding paragraphs a description is given to the reader of some of the pertinent details and the general features of the most important processes attempted for low-temperature carbonization. The fact does not seem to have been as yet generally recognized that such processes are necessarily best suited for treating particular coals under the particular economic conditions governing the markets for the products. Such limitations are, of course, readily recognized by some coal technologists.

The reader should also take note of the complicated equipment employed in a majority of cases to do the carbonization, and therefor the possible practibility of the method from a mechanical standpoint.

Some criticisms have been directed at the process used for obtaining the data published in this thesis. It has been said that the process will fail because of the same engineering factors and other influences experienced by certain processes when put into operation on a commercial scale. For the moment, this matter will be left with the reader to reflect upon, until the latter part of this thesis.

The K-S-G Process. In this process [31] the coal is carbonized in a retort slightly inclined from the horizontal, and consisting of two externally heated concentric drums which are rotated at three-quarters of a revolution

per minute. The outer drum is 72 feet long with a 10 foot diameter and the inner drum is 85 feet long with a diameter of 5½ feet.

The raw coal is fed continuously from a storage bin into the lower end of the inner drum by means of a screw conveyor. Helical flanges carry the coal to the upper end of this drum where it is spilled through open ports into the outer drum. The inner cylinder is maintained at approximately 400° F. by combustion gases circulated around the revolving retort. Upon passing by gravity down the inner surface of the outer cylinder to its lower end, the semi-coke is now picked up by a series of scoops as a finished domestic fuel.

The coal is heated in the inner cylinder to a point below its softening temperature and is then plunged into the upper end of the outer drum which is maintained at a temperature of 1300° F. Heating is accomplished by burning producer gas around the retort, and partly by the exothermic action of the coal. The effect is to "case-harden" the lumps so that its agglomerating properties are reduced. The coal treated is apparently very cohesive at 1300° F., since steam is sprayed between the fuel and the outer retort, and chains are stretched longitudinally in the upper end so that no adhering carbon remains fastened to the retort walls.

The largest low-temperature carbonization plant in

the world was erected in 1929 at New Brunswick, N. J. The plant used the K-S-G process which takes its name from the Kohlenscheidungs-Gesellschaft meaning "Coal Separation Company", a subsidiary of the International Combustion Engineering Company. This American plant was designed to process 250,000 tons per year or about 685 tons daily, employing the basic features of the K-S-G retort operating in Germany. From each ton of raw coal, approximately 1,500 pounds of smokeless fuel containing 12 per cent volatiles, 25 gallons of tar, 3500 cubic feet of 800 B.T.U. gas, and 2 to 3 gallons of light oil were obtained.

The smokeless fuel to be sold on the market as "Disco" was to be above $\frac{3}{4}$-inch in size and amounted to 80 per cent of the 1,500 pounds of semi-coke produced from one ton of the original coal.

The New Brunswick plant has eight retorts of which two were operating in 1929. Each has a capacity of 80 tons daily.

According to the latest authentic information (28), this plant is not in operation. This is explained by the fact that "American coals acted differently from the German coals in this retort, and much trouble was experienced in getting the right blends to give a satisfactory lump coke for domestic use." A lack of "profitable outlets for the tar" was also blamed for the failure of the venture. It seems logical to say that especially the behavior of the American coals and more than likely the operating cost could easily have been determined to a more accurate degree before the plant was built.

The Coalite Process.[32] The well-known "Coalite" process is now regularly producing smokeless fuel under commercial conditions at Barugh, near Barnsley, at the Askern Colliery near Doncaster, and[28] at the South Metropolitan gas works at Greenwich, London, England. The capacity of the first two plants is about 250 tons per 24 hours.

The process originally proposed by Thomas Parker in 1908, consists of heating coking or semi-coking bituminous coal, in narrow cast-iron vertical retorts, to about 1020-1110° F. (550°-600° C.) for 4 hours, "so that the strongly-swelling, heated plastic charge is confined within the retort and a natural compression is thereby given." Each retort consists of a solid casting of 12 tubes in a double row of 6, each 4½ inches inside diameter at the top, tapering to 5½ inches inside diameter at the bottom, and 9 feet long. Thirty-two of these retorts constitute a battery that has a capacity of 50 tons of coal per 24 hours.

The yields obtained by this process are listed as follows:

Smokeless fuel (Coalite), 10-12% Volatile matter	1400 pounds
Gas of 750 B.T.U. per cubic ft.	4000 cu. ft.
Dry tar	18-20 gallons
Light oil from scrubbers	2-3 gallons
Sulphate of Ammonia	Generally not recovered

The writer has a sample of the smokeless fuel produced at Barnsley. It is hard and compact, Fieldner[30]

reports that "less than 5 per cent of the product passes a ½-inch screen; it ignites readily and gives a cheerful glowing fire. In other words, it is an excellent smokeless fuel."

Low-Temperature Carbonization, Ltd., the organization operating and controlling these three plants in England are reported [28] to "have made a small profit in 1932 and to have received a contract from the Government (of England) for supplying some fuel oil and motor fuel made from low-temperature tar."

From the above description of this plant, it is very interesting to note that for a low-temperature carbonization plant to be of commercial size and to produce the smokeless fuel in marketable quantities at a profit, the retorts employed do not necessarily have to be of large diameter and length.

The Illingworth Process.[33] In this method, the coal is heated in a battery of ovens comprising the brick oven proper - - of the horizontal flue type - - within which are disposed special H-section conductors divided into two compartments. These conductors carry the heat from the oven walls into the charge of coal. The ovens are charged from the top.

In 1932, a plant at Pozzolo in Italy and one at Courrieres in France were set into operation. The Italian plant has a daily capacity of 250 tons, complete

with an auxiliary plant for extracting the by-products. As the primary object is to obtain the maximum quantity of solid fuel, coals of relatively low volatile matter (about 30 per cent) are used. The solid product is of high density, contains 8 per cent volatile, 8 per cent ash and has a heating value of 14,750 B.T.U. per pound. It is marketed in several sizes under the name Ricarbon and has been disposed of at prices competing with those of foreign anthracite. The motor spirit is readily saleable at the price of the same from crude petroleum in Italy and the tar oils are finding a market with Italian distillers.

The plant in France was capable of producing 125 tons daily in 1932. It operates along the same general lines as the plant in Italy and yields the same quality of solid fuel which is sold under the name of Anthralux.

The Salerni Process. (34) This process, devised by Piero Salerni, is a variation of a process with which the Department of Fuel Technology, Sheffield University in England has experimented for some time.

The plant consists of a continuous rotary furnace, completely enclosed in an outer casing the base of which rests within a grove providing a water seal. The furnace consists of an outer drum within which are a number of dished circular plates, welded or riveted to one another, so designed as to constitute the heating surface, and

thereby to form peripheral outer chambers for the circulation of heating-gas and cooling gas, also to provide an insulated annular space between the heating chamber and the outer shell of the drum, and to insure that expansions and contractions of the inner drum will not affect the outer shell.

The charge of fuel passes along the furnace by gravity, under the rotation of the furnace, and the finished product is delivered by gravity to a discharge chute. The furnace, slightly inclined, rests on rollers and is driven by gearing in the usual manner. It is heated by hot flue gases which are injected near the discharge end of the retort into a distributing head, integral with the furnace, by an annular nozzle. The vapors of distillation are taken off through a central tube at the discharge end.

The swelling properties of the coal treated are controlled by blending finely ground semi-coke breeze from the process itself with a non-coking coal. As reported, the result is the production of a dense and hard smokeless fuel in the form of spheroidal lumps of "suitable size."

The Rolle Retort.[30] This retort has been used in Germany for many years to distill the rich brown coals for their wax and oil content. As a matter of fact, Germany secured a great deal of her motor fuel and lubricating oil during the World War from this important source.

"The brown coal is charged continuously at the top and descends in a 4-inch annular space between cast-iron rings arranged in venetian-blind fashion that form the inner cylinder and the heated firebrick that form the outer shaft. The distillation products are drawn into the interior space and out through the bottom of the oven. The brown coal residue is a charcoal-like granular material about the size of rice. It is called 'Grudekoks' and is sold as domestic fuel for use in specially constructed stoves and ranges. It is easily ignited and burns without flame with very little excess air."

"In order to reduce cracking of the oils to a minimum, the retort temperature is not permitted to exceed 450°C. The output is only 4 tons per retort in 24 hours. The first cost and the space occupied per ton of material carbonized are high. The use of the Rolle retort is limited to the soft, earthy, non-coking brown coals of Germany, and even there efforts are being made to develop retorts of much higher capacity which employ internal heating by hot gases."

The Carbocite Process. (24) "The Wisner process, otherwise known as the Carbocite process, is a two-stage method carried out in rotary retorts. It has been under experimental investigation for the preparation of boiler fuel at Philo, Ohio.

"The coal is treated in the first or upper retort by

partial oxidization to destroy its agglutinating properties. Thereafter, the coal descends at a temperature of about 600° F. to the second stage, consisting of two parallel retorts, located immediately below. The carbonizing cylinders are heated externally."

The Pittsburgh Coal Company was in 1932 (28) developing the Wisner process under license from owners of the Wisner patent. During 1932 the company was operating a 25-ton-a-day Wisner unit and in 1933 planned to build a 75-ton-per-day unit. This company also controls the patents on the Illingworth process for the United States and Canada.

The Piron-Caracristi Process. (24) (30) This process belongs to the class of internally heated retorts in which carbonization is effected by molten lead.

Each retort consists essentially of a long horizontal tunnel kiln, through which the fuel is transported in thin layers by means of an endless conveyor. The crushed coal is charged into a series of shallow cast-iron pans 36 by 18 by 1 inch deep, which are fastened to the continuous chain. The coal layer is only 5/8 inch deep. Heat is applied to the coal through a bath of melted lead in direct contact with the pans. The temperature of the lead bath is maintained by burning gases in cast-iron flues immersed in the lead, which is contained in a water-cooled tank of clay refractories.

During carbonization the coal particles swell, become pasty, and fuse into a sheet of semi-coke, which detaches itself from the pan during the return of the belt. The volatile matter evolved escapes to the condensers through ducts in the wall of the distillation chamber over the lead bath.

This process was adopted by the Ford Motor Company and attracted much attention. However, Fieldner [30] says, "Preliminary operation of this plant at Walkerville, Ontario showed that all details of design had not been worked out satisfactorily. It is a question if metallurgical science has yet developed a method of constructing, at reasonable cost, a chain mechanism suitable for operation over a long period at a temperature of 650° C."

Carbocoal-Mc Intire Processes. [24] [30] The Carbocoal process, developed by the International Coal Products Company, was put to a commercial test when the United States Government in 1918 gave financial support to build a plant at Clinchfield, Va., having a daily capacity of 575 tons of raw coal.

The Carbocoal process is a multi-stage system, involving primary carbonization in externally heated horizontal retorts in which the distilling coal is stirred by paddles; briquetting of the primary char; and secondary carbonization of the briquetts in an externally heated inclined retort.

The original retort was not practical because the stirrer arms broke under the resistance of the pasty, fused mass of coking coal, and because of other difficulties in design of the metal retort walls.

The Carbocoal retort was subsequently improved by Mc Intire at Fairmont, West Virginia, and is reported to have solved the problems of the former retort. The semi-coke produced is not lumpy, but friable and granular; it therefore requires briquetting and subsequent carbonizing in order to make it suitable for smokeless domestic fuel. Obviously, this additional processing means an added plant manufacturing charge which must ultimately be paid by the consumer, that is, if the venture is to be a financial success.

The retort has a cylindrical shaped bottom, is 16¼ feet long and 8½ feet in diameter, and is placed in a horizontal position. Its lower part consists of V-shaped sections of corrosion resisting iron that are heated by burning gases in the space below. The top part of the cylinder is removable and is made of light boiler plate covered with heat insulating sil-o-cel.

Slack coal is fed continuously into one end of the retort and discharged at the other. The charge is stirred by a central oscillating shaft 30 inches in diameter, carrying arms with paddles. The gases leave the retort at the coal-charging end.

The operating temperature is only 450° C.

The Me Ewen-Runge Process. (24) (30) This process based upon the invention of Mc Ewen, is controlled by the International Combustion Engineering Corporation. The process was largely developed by Runge at the Lakeside Station of the Milwaukee Electric Railway and Light Company.

By this process, pulverized coal is treated by an internal heating method such that the carbonized residue can be used directly as pulverized fuel without further pulverizing.

The process is carried out in two vertical superimposed steel cylinders, each about 30 feet in length and 6 feet in diameter. The metal cylinders are lined with refractory to protect them from the heat.

The upper cylinder constitutes the primary retort, wherein the coal is treated by preheating or partial oxidization to destroy its coking property; the lower cylinder forms the secondary retort, where the coal is carbonized.

Pulverized coal is introduced in at the top of the primary retort through four feed pipes which project about 8 feet into the cylinder and which are fed by screw conveyors. The raw coal then falls freely to the bottom of the primary retort against a current of hot air, or products of combustion. This hot pretreated coal, now

robbed of its agglutinating power, is fed by screw conveyors through four additional feed pipes into the top of the secondary retort, where it again falls countercurrent to a stream of ascending hot inert heating gas introduced into the bottom of the cylinder. The temperature of the gas in the first retort is kept at 320° C., while the gases in the secondary retort are maintained at 570° C. The resulting hot, pulverent semi-coke collects in a cooling chamber below the secondary chamber.

The process is continuous, requiring only six minutes for both stages, and the units built at Milwaukee were capable of producing 210 tons per day.

Fieldner [30] says that "the process goes to the ultimate extreme in rapid transfer of heat to the coal and has possibilities of high throughput in equipment of relatively low cost; but the mechanical difficulties to be solved seem very great especially the separation of the fine dust from the vapors."

Lurgi Process. [35] The first American plant using the German "Lurgi" process was erected near Dickinson, North Dakota by the Lehigh Briquetting Company to treat North Dakota lignite. The carbonized coal residue, with the by-product pitch as a binder, is pressed into briquets, which are claimed to burn smokelessly.

North Dakota lignite is a non-coking, disintegrating

type of coal, and is processed in sizes ranging from ¾ inch to 4 inches. The temperatures employed for the destructive distillation vary from 600° to 620° C. (1112° to 1148° F.).

This plant was operating [28] in 1932, after being closed for some time. Raw lignite of about 6,400 B.T.U. is carbonized by the Lurgi Process, forming a char which is pulverized and briquetted, making a fuel having about 13,000 B.T.U.

The Hayes Process. [36] With the object of utilizing slack bituminous coal, the first Hayes process carbonizing plant was built at Moundsville, West Virginia, in 1927. It had a capacity of 50 tons of coal in 24 hours.

A new unit, built with many improvements over the first one, and having 50 tons of daily capacity, has been operating successfully up to date, (1932).

The retort consists of an alloy steel tube 17 inches in diameter and 20 feet long. This tube is placed in a furnace setting and is supported by rollers on each end; it is rotated at a speed of 1½ revolutions per minute.

Within the retort is a specially constructed screw conveyor driven by a train of gears which creates a progressive oscillating motion. Because of the forward and backward motion imparted to the fuel in this manner, the coal has a theoretical travel of 240 feet in passing through the 20 foot length of retort.

In the present unit, seven of these retorts are externally by means of gas burners placed on the underside of the furnace setting, and each retort is entirely independent in its operation of the other six.

The residual product is a char which is briquetted with a coal-tar pitch binder. The briquettes are pillow shaped and weigh about 2½ ounces.

At the feed end, the heating gas temperature range from 760° to 871° C. (1400° to 1600° F.) and produces a furnace temperature at the discharge end of 590° to 700° C. (1094° to 1292° F.).

This plant [28] has been operating intermittently in accordance with market demands for the product.

SCOPE OF PRESENT INVESTIGATION

The pressing need for an economical source of solid and gaseous smokeless fuel, to eliminate the smoke from Salt Lake City and other cities as well, has now been pointed out. The principles of destructive distillation as known to science and engineering for producing these smokeless fuels, has also been given in some detail, and various individual processes embodying the same general principles have been outlined.

The most logical step has been to determine what can be done by way of low-temperature carbonization to make suitable smokeless fuels from the coals of the Rocky Mountain Coal Province, in order that the principal cities

within this area might be freed of the deplorable smoke nuisance.

Mr. L. C. Karrick, an alumnus of the University of Utah, while serving as a United States Government refinery engineer and fuels technologist, has studied this problem for many years. Beginning in 1919 he directed an investigation of the carbonaceous earth materials as the possible future source of the nation's oil supply. His work was headquartered at the Salt Lake Station of the United States Bureau of Mines located on the campus of the University of Utah. The State of Utah also cooperated with funds for a number of years while the late Simon Bamberger was Governor.

After many years of intensive and thorough research, Mr. Karrick formulated a number of methods for treating these Western coals, and particularly the coals of Utah. During this period he also obtained a basic understanding of the principles of distilling the carbonaceous materials in general throughout the State, namely-coals, oil shales, asphalt, and other hydrocarbons.

The method of low-temperature carbonization of coal used by the writer for this study is one of several processes of Mr. Karrick's pertaining to the destructive distillation of many other earth materials which yield hydrocarbons of value to the State.

These processes are covered by patents either now

issued or applied for, and are being offered to the present Research Foundation of the University of Utah which was initiated by Mr. Karrick in order that the School of Mines and Engineering would henceforth be endowed with ample funds for valuable research work in the interest of the public.

Although much time has been given to a study of Utah coals as the source material for a smokeless fuel, yet there has been no paper written which has treated this subject in every detail. That is, the three products of destructive distillation, namely, (1) solid smokeless fuel, (2) crude oil, and (3) artificial gas, have not been studied in detail in relation to their production from the principal coal bodies of the Intermountain Region.

For this reason, the writer undertook to make a study of the subject which was to cover as much of the field as possible in one year. Approximately six months were required to design and construct the coal-processing plant, and four months to obtain the coal products and operating data.

The object then of this investigation was to obtain data relative to the following items:

1. The adaptability of the coals to the process.

2. The heat required, the steam consumption*, the time necessary to distill the coal, and the mechanism of the heat transfer.
3. The yields of solid smokeless fuel, crude oil, and artificial gas.
4. Physical and chemical properties of the smokeless fuel versus the raw coal.
5. The heating efficiency of the smokeless fuel versus the raw coal in typical coal-burning appliances.
6. The constituents and heating value of the artificial gas.
7. Information as to the life of material involved in the construction of the superheater and retort.
8. Data concerning the quantity and quality of the products obtainable from the crude oil.

These items, as they pertain to the bituminous and subbituminous coals of Utah, were to be particularly investigated.

* As will be explained later, superheated steam is the heat-carrying medium by which the coal is destructively distilled.

DESCRIPTION OF COAL CARBONIZATION PLANT

For the purpose of carrying out this investigation, a small carbonizing plant capable of yielding commercial coal products, was erected in the Mechanical Engineering Laboratories of the University of Utah. Figure 3 is a schematic elevation of the plant showing all the component parts, connections, and piping. Figure 4 is an actual photograph of this plant.

The major parts of the plant consisted of the superheater, the coal retort, the three condensers, the condensate decanter, the condensate measuring tank, the gas scrubber, the gas meter, the gas sample storage tank or gasometer, and the potentiometer.

Brick was used in constructing the superheater combustion chambers, (f) in which gas was burned. Broken refractory served as a material upon which surface combustion took place. The gas burners consisted of gas jets (j) and air mixing tubes (k), the jets being drilled pipe caps and the tubes 8-inch lengths of 3-inch pipe.

Two burners were used in each side of the combustion chamber which was divided longitudinally into 2 parallel compartments approximately 6x8 inches in cross section. Instantaneous sight control of the amount of gas burned was provided by the manometer, (i) which indicated the pressure of the gas delivered to the burners by regulat-

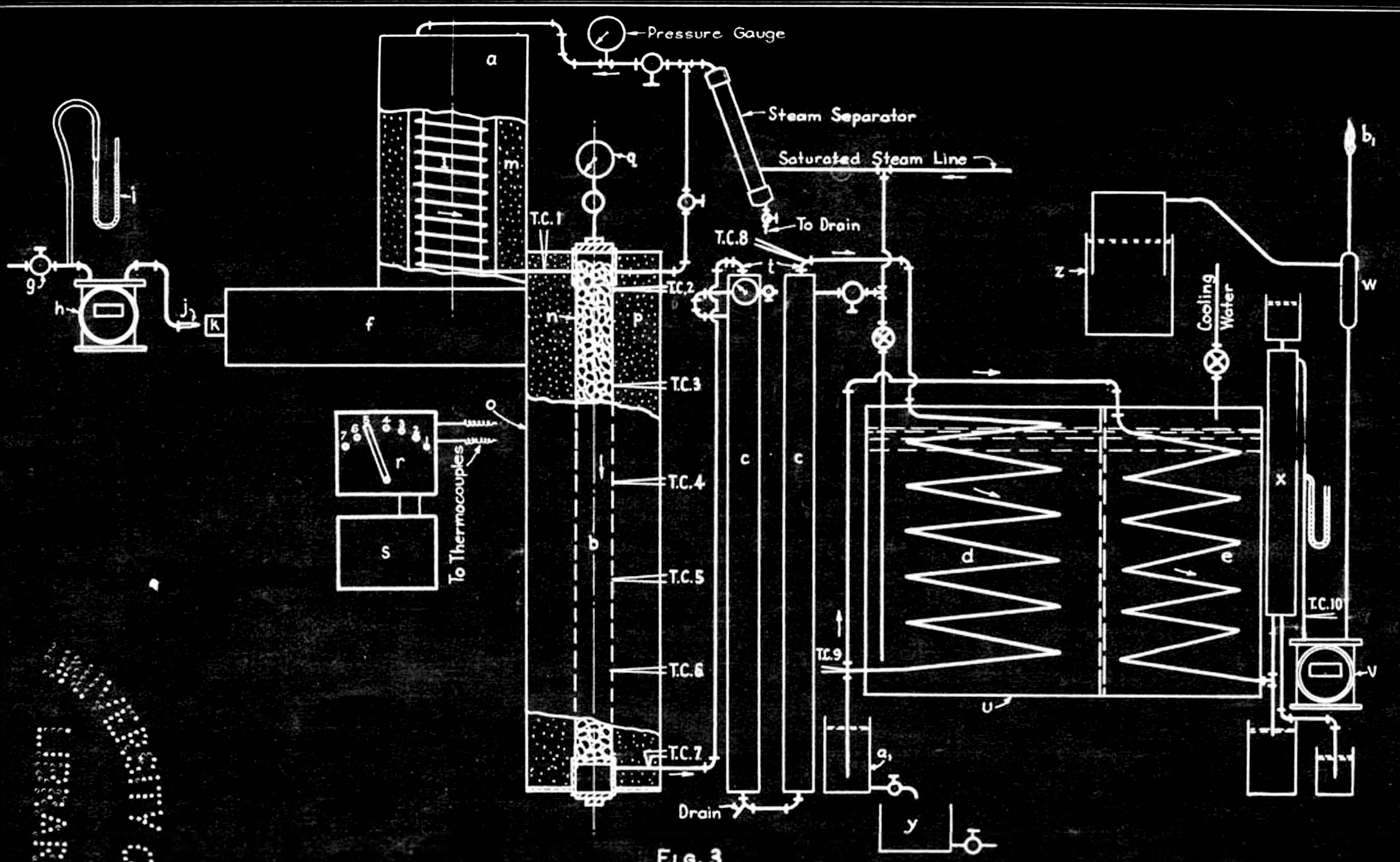
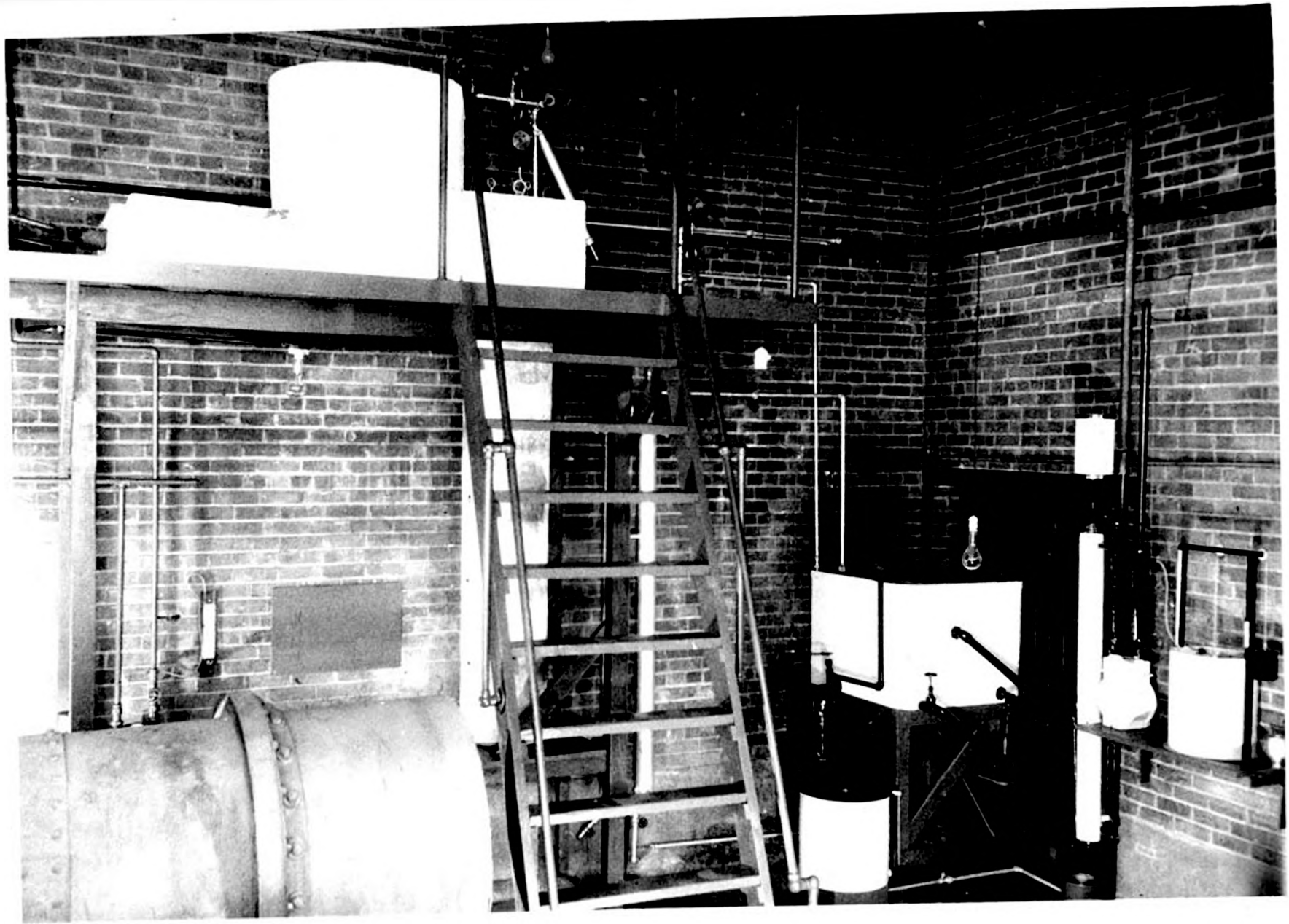


FIG. 3

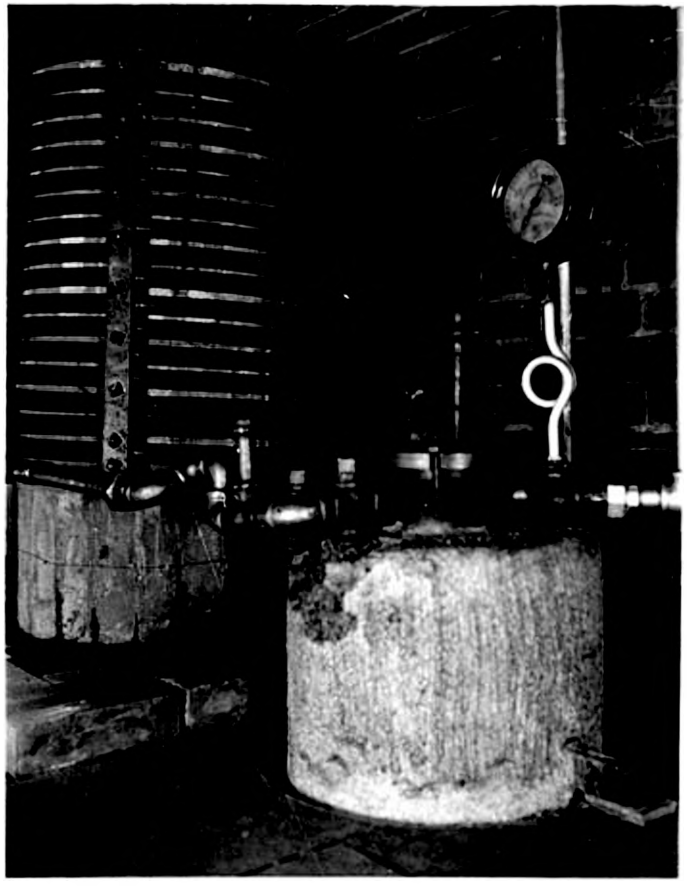
SCHEMATIC LAYOUT OF TEST PLANT



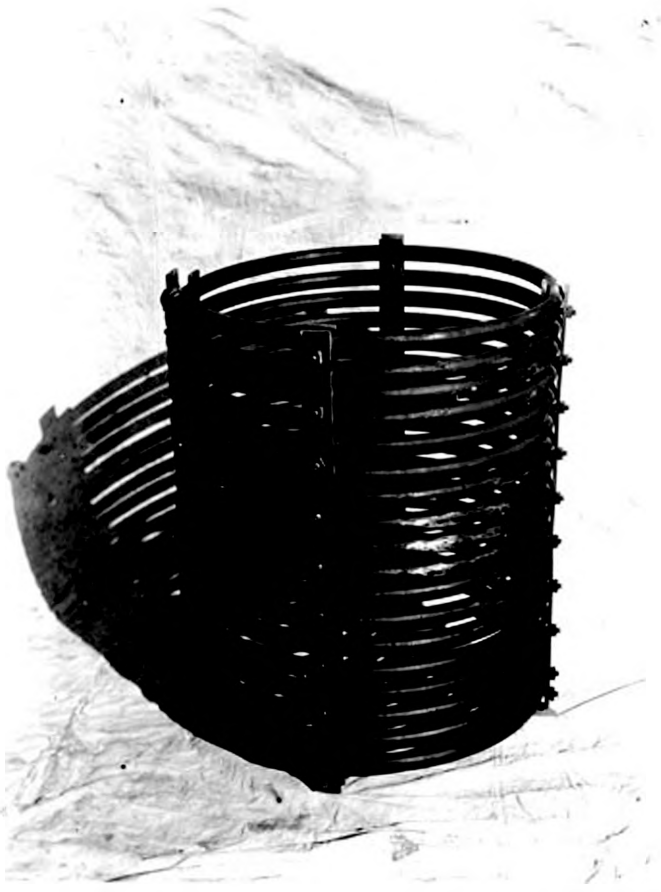
. . 4. View of the Coal Carbo[illegible] Plant used for the Present Investigation

ing valve, (g) the body of the superheater consisted of a 23 inch diameter coil of ¾-inch black iron pipe (l) approximately 100 feet in length and standing 27 inches high. The coil was set in the annular space between two concentric columns built of arch brick (m). Figure 5b shows the coil with the suspension straps, and Figure 5a shows the coil in place surrounding the inner column of brick. Cross bars bolted to the top of the suspension straps hold the weight of the coil upon the top of the central brick column. This arrangement allowed thermal expansion of the coil in a downward direction. Saturated steam was admitted into the superheating coil at the top where there was provided a steam gage to show the pressure of the steam entering the coil. A steam flow regulating valve and a steam separator are also provided at the superheater inlet.

The coal-distilling retort (b) consisted of a thin-walled cylinder (n) 8 feet long, of 18-gage black iron with welded seams approximately five inches in diameter at the top and slightly larger at the bottom. On the ends of the retort were welded 5-inch pipe couplings with ¾-inch plate covers to serve as removable closures. Figure 6a is a photograph of one of these caps. The outer ends of the pipe couplings were machined to fit into packed grooves in the plate covers. The plates were also provided with receiving slots for three holding bolts pivoted in



(a) View of the Superheater Coil in Place



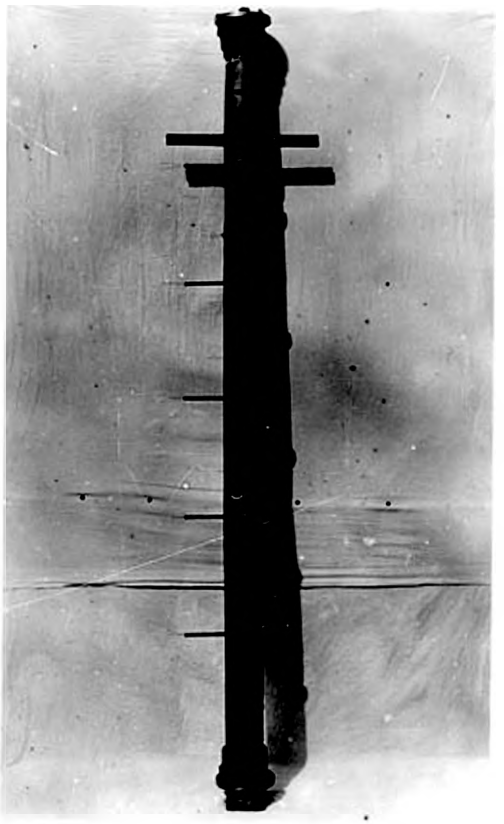
(b) View of the Superheater Coil

Fig.5

lugs welded to the pipe coupling. This arrangement permitted quick and easy removal of the cover plates. The retort was supported by horizontal straps of iron welded at their centers to the sides of the retort wall as in Figure 6[b], at a point 18 inches below the top cover plate. The straps rested upon the platform shown in the photograph, Figure 4. Thus, the greater portion of the thermal elongation of the retort took place in a downward direction so that the thin metal walls were kept under tension and thereby preventing buckling. To prevent strains in the equipment due to this elongation and to the elongation of the superheater coil, the connections between the retort and the superheater coil, also between the retort and the first condenser, [c] were made with assemblies of pipe elbows. The top of the retort was provided with three connections: the superheated steam inlet, the saturated steam inlet, and a low-pressure steam gage serving to indicate the pressure within the retort. The superheated steam inlet was provided with two cast iron quarter-turn cocks which allowed the superheated steam to be by-passed to the atmosphere when not passing into the retort. The saturated steam inlet was connected to the superheater steam supply line through a steam valve. Saturated steam was used to cool the retort and contents after the coal charge had been treated.

Five chromel-alumel thermocouples (abbreviated "T.C."

(a) View of a Retort Cap



(b) View of the Retort

Fig. 6

on Figure 3) were encased in three-eighths-inch copper tubing and brazed to the sides of the retort at 16-inch intervals as shown in Figure 6[b] . One thermocouple was inserted in the superheated steam line at the top of the retort and one at the bottom in the vapor outlet to the first condenser, making seven thermocouples in the retorting chamber.

The retort was insulated against heat losses with a 6-inch layer of expanded mica insulating material. This was applied in a plastic state and reinforced with wire mesh. Slots were provided in the insulation in order that the thermocouple tubes were free to move with expansion and contraction of the retort. The insulation was supported three feet above the floor by a platform. The lower six inches of the retort and the vapor outlet connections protruded through this platform allowing free vertical movement of the retort due to thermal expansion, also providing easy access to the lower retort cap for discharging the treated coal. The upper end of the retort and the superheated steam connection were surrounded with a brick chamber connected to the outer wall of the superheater as shown in Figure 4. The chamber was filled with ground asbestos-magnesia insulating material up to within about one inch of the lower edge of the retort cover plate. Two blocks were cast of this insulating material to cover the top of the retort and fill the upper part of

this chamber. Wire handles attached to these blocks permitted their easy removal for access to the upper retort cap when charging the retort with raw coal.

Vapors from the bottom of the retort were carried to the top of "hot" condenser (c) through a vertical $\frac{3}{4}$-inch pipe. The condensed high-boiling hydrocarbons were removed at the drain provided, and the remaining vapors were then carried out from the top of the second tube of this condenser to the water-cooled condensers (d) and (e).

Condenser (c) consisted of two vertical two-inch pipes (t) 6 feet long, joined at their lower ends and containing a spiral metal ribbon which caused rotation of the vapor stream and impingement of liquid particles against the tube walls. Each pipe was surrounded by a steam jacket of 4-inch pipe with steam inlets, blow-off, pressure gauge and valves for regulating the steam pressure, and therefore the temperature on the 2-inch tube walls. An oil drain was provided in the bottom of the connection between the two 2-inch tubes. This condenser thus provided a means of condensing out of the vapor stream only the high-boiling oil vapors while preventing any condensation of water vapor. By thus removing the high-boiling oils, which were found to be heavier than water, the remaining oils and water could be condensed together in another condenser and thereafter separated by decantation. Without such selective condensation this crude oil, which has approximately the same specific gravity as water, could have been

separated from the water only with great difficulty. A thermocouple was provided at the vapor outlet of this condenser.

Condensers (d) and (e) consisted of two coils of 2-inch pipe, placed in series, occupying separate compartments in the condenser box (u). Cooling water flowed in counter direction to the vapors being cooled, the condensate from condenser (d) being maintained above 70 degrees Fahrenheit so as to prevent the condensed waxy oils from congealing and clogging the coils. A thermocouple was provided at the outlet of this condenser for the purpose of observing this temperature. The oil and water condensates from condenser (d) were drawn off under a liquid seal into the decanter (a) which was provided with an oil overflow, while the water settled to the bottom and was permitted to drain into the tank (y) fitted with a water level tube calibrated in pounds. The remaining vapors and gases from condenser (d) were passed into condenser (e) surrounded by cold water in which the light oils were condensed, the latter being collected in a liquid-sealed container.

The non-condensable gases were then passed up through the scrubbing tower (x) to remove the naptha fog carried in the gases. The tower consisted of a 6 foot length of 4-inch pipe filled with sized gravel over which absorption oil trickled in counter-flow to

the gases. The used oil was drained from the base of the tower and "topped" to collect the naphtha. The naphtha-free gases were then passed through meter (v) provided with a thermocouple and a manometer, and thence through the sampling tube (w) to the torch (b_1) where they were burned. The sampling tube was a sheet metal cylinder three inches in diameter and eighteen inches long containing at the upper end a flat spiral coil of copper tubing placed in a horizontal plane and in which were drilled several one-sixteenth inch holes with their axes parallel to the flow of the gases. The large cross-section of the sampling tube assured stream-line flow of the gases and by this device approximately one - one hundredth part of the gases was diverted into the gas holder (z). The gas holder of 1 cubic foot capacity, was composed of an inverted rising and falling cylinder, provided with adjustable counter-weights, and sealed at the bottom in a salt water tank.

Electric spark gaps were provided for lighting the gas burners of the superheater, also for lighting the generated coal gases, which were burned at the torch instead of using them for fuel purposes in this coal-treating plant. Gas sampling bottles were provided, also a Burrell-Orsat gas analyzer. Oil samples were collected in air-tight cans for future refining studies.

OUTLINE OF PLANT TESTS

General. The scope of the plant tests has been mentioned earlier in this work. In order to facilitate the investigation, these tests were divided into "preliminary" and "detailed" tests.

Preliminary Tests. The primary purpose of making the preliminary tests was to secure sufficient data which would indicate the adaptability of important coals to retorting by the process and also to provide information that would indicate the quantity and physical characteristics of the smokeless fuel as well as the yields of crude oil and artificial gas.

This information would then permit the selection of the coals that would later be studied in detail.

Detailed Tests. These tests were made in order, (1) to determine the effect of distilling temperature upon the resulting products, (2) the heat requirements, (3) the amount of steam required, and (4) the mechanism of the heat transfer to the coals chosen on the basis of the preliminary tests.

METHOD OF MAKING PRELIMINARY TESTS

General. In following the succeeding paragraphs, the writer suggests that the reader use the diagram of the plant set-up as given by Figure 3 opposite page 71 .

In order to make the results of these tests compar-

able, the temperature of the superheated steam used was always at or very near 650° C. (1202° F.). The size of the coal lumps was always within the range of 2-inches to ¾-inch for the same reason. Reading of all instruments were made every fifteen minutes during the distilling period.

Preparation of the Coal. The sample previously sized below 2-inches was thoroughly mixed by coning and re-coning which was accomplished by depositing each shovel full of coal on top of the preceding one. The cone was flattened, its apex being pressed vertically down with a shovel or board, so that after the pile was quartered, each quarter contained a true average of the material. The flattened mass of uniform thickness and diameter was then marked into quarters by two lines that intersected at right angles directly under a point corresponding to the apex of the original cone. The diagonally opposite quarters were then shovelled into the container provided for this purpose, and the space that they occupied brushed clean. The coal remaining was successively coned, and quartered until the sample was reduced to approximately 10 pounds.

The coal which had been shovelled into the container was first screened over a ¾-inch screen; the plus ¾-inch size was then sacked and labelled. The coal which passed the ¾-inch screen was screened over a ½-inch screen; the

plus ½-inch portion being sacked and labelled. Both of these portions were reserved for carbonization purposes, and that coal passing the ½-inch screen was sacked and stored for possible later studies.

The 10 pound portion obtained by quartering the original sample was crushed to 1/8-inch, and passed through a small riffle sampler, having approximately twenty-four 3/8-inch openings, to further reduce the sample to approximately one pound. This was the laboratory sample and was kept in a labelled Erlenmeyer flask provided with a rubber stopper sealed with paraffin wax.

The weight of a cubic foot of the coal to be treated was obtained by using the A. S. T. M. Standard method described in Appendix IV of this thesis.

Charging the Retort. The retort was filled full with a weighed portion of the coal sized from 2-inches to ¾-inch as described above. The coal was allowed to drop into the top of the retort from a charging funnel, no attempt being made to prevent breakage of the coal as it dropped into the retort.

Water in the Decanter. Eight pounds of water was held in the decanter at the beginning and at the end of the run.

Miscellaneous Items Which Were Checked Before the Test was Made. The plugs in the cocks of the superheated steam lines, and the threads of the bolts at the top of

the retort, were "worked in" with the standard graphite mixture as lubrication seemed desirable. The standard graphite mixture consisted of finely powdered graphite and enough water to make a product of creamy consistency.

The retort lids were tightly bolted to the retort.

A bucket was provided under the oil drain from Condenser No. I.

Steam at 1 to 5 lbs. pressure was always passed into the jacket of Condenser No. 1.

The temperature of the water in Condenser No. 2 was kept at approximately 60° C.

Sufficient water was always held in the condensate tank so that the gauge glass could be read. The drain valve from this tank was closed before the test was started.

Ample cold water was kept running into Condenser No. 3 to prevent the cooling water surrounding the coils from raising above 25° C.

Enough water was placed in the 1-liter oil condensate flask from Condenser No. 3 to insure a good water seal.

The valve in the gas line from Condenser No. 3 was opened wide.

The tank at the top of the naphtha scrubber was filled with absorption oil, "topped" at 200° C. A receiver was provided for the naphtha-laden oil. Approximately 40 cc. of gas oil per minute was allowed to pass down through the

scrubber as soon as the flow of generated gas began.

All of the air from the gasometer was discharged. The gasometer was then connected to the system and was at all times so counter balanced as to be under a slight suction pressure. There was sufficient salt water present to insure a good seal.

A glass bottle of at least 200 cc. capacity was provided, having a 2-hole rubber stopper with delivery and exit tubes. This bottle was filled with salt water, and was used at the end of the test to store the laboratory sample of generated gas.

Thermocouple Readings. These reading were made every 15 minutes with chromel-alumel thermocouples and a Leeds and Northrup Potentiometer. Particular attention was paid to the superheated steam temperature which was measured by one thermocouple surrounded by the superheated steam as it entered the retort.

Pressures. While the superheated steam was being bypassed to the atmosphere, the pressure of the saturated steam entering the superheater was 15 lb. per sq. in. gauge. When the superheated steam was directed into the retort, this pressure was approximately 20 lb. per sq. in. gauge.

The maximum pressure of the superheated steam was about 15 lb. per sq. in. gauge.

The maximum pressure of the steam to Condenser No. 1 was about 10 lb. per sq. in. gauge; the minimum about 1 lb. per sq. in. gauge.

The Flow of Superheated Steam During the Distilling Period. The superheated steam was passed into the retort until the rate of generation of the artificial gas began to decline and the color of the flame changed from orange to light yellow, indication nearly complete distillation of the charge. When No. 7 thermocouple read from 360° C. to 400° C. the flow of steam was stopped.

At this moment, ie., just as soon as the steam was no longer admitted to the retort but was by-passed to the atmosphere, all of the thermocouples were read as quickly as possible. Then the gas supply to the superheater was discontinued, and the gas burner mixing tubes plugged with wet asbestos so as to prevent cold air from entering the superheater setting.

When the condensed superheated steam stopped flowing from the decanter, the gage on the condensate tank was read. The tank was then drained. All thermocouples were read again as quickly as possible.

The flow of Saturated Steam During the Dry Quenching Period. As soon as practicable after shutting off the superheated steam, the saturated steam was admitted to the retort for the purpose of cooling the semi-coke. The drain valve from the condensate tank had been previously closed. The gage glass on this tank was then read. The saturated steam was passed through the retort at a pressure below 15 lb. per sq. in. gauge until No. 7 thermo-

couple read a maximum of 225° C. The steam was then shut off and the gage on the condensate tank read. All thermocouples were read at this point.

Crude Oil. The water in the oil from Condensers No. 2 and No. 3 was decanted as much as possible and due correction was made for this water in measuring the superheated steam used. The weight of the collected oil was then determined and recorded as the weight of wet crude oil. The oil was stored in an air tight can and labelled for future study.

Artificial Gas. A sample of the gas from the gasometer was collected in the bottle provided, by displacing the salt water. The bottle was labelled, and then tightly stoppered and sealed with sealing wax.

The Coal Residue From the Retort. The coal residue was permitted to slide from the bottom of the retort into a long trough with the minimum of breakage. The coal was then weighed and spread over a clean area on the floor in one continuous line as it came from the retort, and allowed to cool. The weight of a cubic foot was determined and thereafter the residue was stored for future reference.

PRELIMINARY TESTS

The laboratory data and the tabulated results obtained for each of the preliminary tests are presented on the ensuing pages. The writer has tried to present the data so that it will "speak for itself" and has supplemented it with a few salient remarks concerning the coals and the conditions under which they were processed.

At this point, it should be recalled that when most coals are heated in the absence of air, they assume a plastic state. In this condition the coal lumps tend to fuse together or they may disintegrate, to a degree depending upon the characteristics of the particular coal.

The knitting of the lumps into more compact masses decreases the area available for the flow of superheated steam, increases the friction while reducing the steam flow, and therefore, lengthens the time required for carbonization. Higher steam pressure can, of course, compensate for the retarded steam flow.

The word residue as used herein, refers to the smokeless fuel.

TEST NO. 1

The coal used for this test and the following three tests was furnished by the Utah Fuel Company. Representative samples of each coal were obtained directly from the mines.

Test No. 1 was made on coal from the Castlegate No. 2 mine, "D" Seam, located in Carbon County, Utah.

Some difficulty was experienced in maintaining a steady flow of heat from the superheated steam to the coal. As previously explained, this was due to the coal lumps softening and knitting together so as to decrease the rate at which the superheated steam could pass through the retort. However, this action was not of great importance, since on the average only 1½ hours were required to carry through the destructive distillation.

The smokeless fuel was removed from the retort without much difficulty. Because of the slight fusing properties of the coal, it was necessary to prod the finished product from the retort. The product showed no evidence of adhering to the retort walls but the coal mass had knitted together and arched against irregularities in the walls.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. I

Date December 23, 1933 Coal Castlegate No. 2 -"D" Seam
Size of Coal -1 1/2" to +3/4" Superheated Steam Temp. 650 oC.

Coal and Residue

1. Weight of raw coal charged, pounds..... 49.25
2. Weight of residue from the retort, pounds..... 34.50
3. Loss in weight, pounds 14.75 ,percent of total 30.0 , pounds per ton of raw coal..... 600
4. Weight of raw coal, pounds per cu. ft..... 40.0
5. Weight of residue, pounds per cu. ft..... 26.5
6. Physical properties of the residue:
   (a) color dull luster, black
   (b) texture porus, with deep-seated expansion cracks
   (c) hardness fair

Gas

7. Total gas generated, cubic feet..... 64.86
   Cubic feet per ton of raw coal..... 2630

Crude Oil

8. Weight of crude oil, pounds..... 5.88
   Pounds per ton of raw coal..... 239

Superheated Steam

9. Apparent weight of steam used, pounds..... 82.0
   Pounds per ton of raw coal..... 3330

Saturated Steam

10. Weight of saturated steam used, pounds..... 62.0
    Pounds per ton of raw coal..... 2520

PROXIMATE ANALYSIS OF COAL*

Moisture	3.5	Volatile Matter	43.5
Fixed Carbon	48.0	Ash	5.0
	Sulphur	0.6	

*Source of Analysis:
Utah Fuel Company

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. I

Date December 23, 1933 Barometer 25.36 in. of Hg.
Coal Castlegate No.2-"D"- Seam
Size of Coal -1 1/2" to + 3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	49.25
Weight of residue from the retort, pounds	34.50
Weight of raw coal, pounds per cubic foot	40.0
Weight of residue, pounds per cubic foot	26.5
Final reading of gas meter No. I, cubic feet	68.56
Initial reading of gas meter No. I, cubic feet	3.7
Superheated steam:	
Final reading of condensate tank, pounds	85.0
Weight of water from Condensers No. 2 and 3	----
Initial reading of condensate tank, pounds	3.0
Saturated steam:	
Final reading of condensate tank, pounds	74.0
Initial reading of condensate tank, pounds	12.0
Weight of crude oil, pounds	5.88

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
12:53	646	80	80	67	89	83	101	101	32	11		12	0	13		
1:00	650	202	113	104	99	102	101	101	36	8		15	4	10		Gas on at
1:15	654	441	328	236	172	135	103	103	34	8		16	6	12.5		1:03
1:30	650	526	452	394	319	238	203	112	32	8		19	9	12.5		
1:45	650	526	476	432	385	298	241	110	61	13		9	4	12.5		
2:00	660	550	512	478	444	390	332	113	78	13		17	8	11.0		
2:18	650	530	492	462	438	394	298	102	41	8		--	0	0	0	Sup.Stm.Off
2:25		462	473	455	443	418	364	127	40	11		--		0	9	Sat.Stm.On
2:34		220	313	338	414	422	399	167	38	11				11	9	
2:45		122	181	204	266	312	328	176	34	14				7.5	12	Gen.Gas Off
3:00		101	107	115	115	142	166	151	33	11				10	11	Sat.Stm.Off

TEST NO. 2

This test was made on coal from the Castlegate No. 3 mine, "F" Seam.

It was found that this coal fused upon treating to a greater extent than did the sample from the Castlegate No. 2 mine. As a result, the time required for distillation was increased approximately 50 per cent over that required in Test No. 1. Also, the charge of smokeless fuel was compressed into a more compact mass.

However, from the standpoint of texture and hardness, this coal gave a much better smokeless fuel than did the coal from the Castlegate No. 2 mine.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 2

Date January 3, 1934 Coal Castle Gate No. 3 "F" Seam
Size of coal -1¼" to +3/4" Superheated Steam Temp. 650 °C

Coal and Residue

1. Weight of raw coal charged, pounds..... 47.0
2. Weight of residue from the retort, pounds..... 32.0
3. Loss in weight, pounds 15, percent of total 31.9, pounds per ton of raw coal.... 639
4. Weight of raw coal, pounds per cu. ft..... 40
5. Weight of residue, pounds per cu. ft..... 24
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture dense, very few surface cracks
   (c) hardness very good

Gas

7. Total gas generated, cubic feet..... 59.55
   Cubic feet per ton of raw coal..... 2540

Crude Oil

8. Weight of crude oil, pounds..... 5.94
   Pounds per ton of raw coal..... 253

Superheated Steam

9. Apparent weight of steam used, pounds..... 70
   Pounds per ton of raw coal..... 2980

Saturated Steam

10. Weight of saturated steam used, pounds..... 54.5
    Pounds per ton of raw coal..... 2320

PROXIMATE ANALYSIS OF COAL*

Moisture	2.5	Volatile Matter	42.3
Fixed Carbon	49.5	Ash	5.7
		Sulphur	0.6

*Source of Analysis:
Utah Fuel Company

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 2

Date January 3, 1934 Barometer 25.50 in. of Hg.

Coal Castlegate No. 3 "F" Seam

Size of Coal -1½" to + 3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	47.0
Weight of residue from the retort, pounds	32.0
Weight of raw coal, pounds per cubic foot	40.0
Weight of residue, pounds per cubic foot	24.0
Final reading of gas meter No. 1, cubic feet	147.05
Initial reading of gas meter No. 1, cubic feet	87.5
Superheated steam:	
Final reading of condensate tank, pounds	71.0
Weight of water from Condensers No. 1 and 2	
Initial reading of condensate tank, pounds	1.0
Saturated Steam:	
Final reading of condensate tank, pounds	78.0
Initial reading of condensate tank, pounds	23.5
Weight of crude oil, pounds	5.94

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		12	12	12	12	12	12	61	25	16						
11:43																Sup. Stm.
11:44	650	68	68	52	77	63	96	96	44	17		12	1	4		on
11:55																Gas on.
11:59	650	396	234	174	116	96	96	94	57	16		14	4	4½		
12:15	659	497	405	318	258	184	160	100	41	16		16	6½	5		
12:30	660	551	476	326	380	296	226	104	36	16		20	13	6		
12:45	650	522	466	424	384	310	250	104	29	17		12	9	8		
1:00	654	522	466	424	398	326	272	104	50	18		15	9	7½		
1:15	650	537	483	446	414	360	305	106	37	18		18	10	7½		
1:30	654	516	471	441	410	376	298	102	38	16		15	10	8		
1:45	650	512	464	431	408	392	310	103	36	17		11	7	7½		
2:00	645	523	480	446	424	412	338	104	34	16						
2:09	656	537	492	435	414	319	98	36	16			20	0	0		Sup. Stm.
	T.C.		No.	7	is	low	but	was	359	at	2:08					off at
2:16		499	462	426	398	378	265	86	33	16		20	0	0		2:08
2:20		419	452	436	414	401	317	116	33	16		20	0	5	10	Sat. Stm.
2:30		226	317	354	379	405	376	154	38	19		20	0	7	15	on
2:45		154	197	220	252	286	316	163	38	16		20	0	6	7	
3:02		128	147	157	171	197	213	126	30	16		20	0	0	6	Sat. Stm.
																off

TEST NO. 3

Coal from Clearcreek in Carbon County, Utah, was used for this test.

This coal was found to be well suited to processing. It caused excessive back pressure of the steam in the retort, and thus it permitted the distillation period to be reduced from previous values to one hour.

This coal was observed to be somewhat friable before processing. This characteristic seemed to have an influence upon the hardness of the smokeless fuel, since it was also slightly friable but of fair hardness.

LOW TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 3

Date January 5, 1934 Coal Clearcreek

Size of coal -1½" to +3/4" Superheated Steam Temp. 650 °C

Coal and Residue

1. Weight of raw coal charged, pounds..... 47.5
2. Weight of residue from the retort, pounds..... 31.5
3. Loss in weight, pounds 16.0, percent of total 33.7, pounds per ton of raw coal.... 674
4. Weight of raw coal, pounds per cu. ft..... 40.5
5. Weight of residue, pounds per cu. ft..... 25.5
6. Physical properties of the residue:
   (a) color black. dull luster
   (b) texture fairly dense - very large surface cracks
   (c) hardness fair. slightly friable

Gas

7. Total gas generated, cubic feet..... 63.15
   Cubic feet per ton of raw coal..... 2660

Crude Oil

8. Weight of crude oil, pounds..... 5.92
   Pounds per ton of raw coal..... 249

Superheated Steam

9. Apparent weight of steam used, pounds..... 87
   Pounds per ton of raw coal..... 3660

Saturated Steam

10. Weight of saturated steam used, pounds..... 53
    Pounds per ton of raw coal..... 2235

PROXIMATE ANALYSIS OF COAL*

Moisture	6.1	Volatile Matter	45.7
Fixed Carbon	44.7	Ash	3.5
		Sulphur	0.5

*Source of Analysis:
Utah Fuel Company

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 3

Date January 5, 1934 Barometer 25.52 in. of Hg.
Coal Clearcreek
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds..... 47.5
Weight of residue from the retort, pounds..... 31.5
Weight of raw coal, pounds per cubic foot..... 40.5
Weight of residue, pounds per cubic foot..... 25.5

Final reading of gas meter No. I, cubic feet..... 111.75
Initial reading of gas meter No. I, cubic feet..... 48.6

Superheated steam:
Final reading of condensate tank, pounds..... 79.0
Weight of water from Condensers No. 2 and 3..... 13.0
Initial reading of condensate tank, pounds..... 5.0

Saturated steam:
Final reading of condensate tank, pounds..... 77.0
Initial reading of condensate tank, pounds..... 24.0

Weight of crude oil, pounds..... 5.92

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		15	15	15	15	15	15	15	24	18						
11:53																Sup.Stm.On
11:54	645	61	61	38	82	76	100	100	38	18		16	0	19		
12:00	630	233	127	93	101	100	106	96	56	15		18	5.75	3		
12:15	650	455	390	258	211	165	108	102	76	19		19	7	10		
12:30	654	534	486	398	367	304	234	111	62	19		20	8.5	7		
12:45	650	559	532	464	458	412	368	170	38	18		20.5	9.5	9		
12:50																Sup.Stm.Off
12:55		512	478	428	410	368	278	126	28	16						
12:58																Sat.Stm.On
12:59		502	470	418	400	361	304	133	28	17						
1:01		442	478	446	446	406	362	140	32	16		20	0	6	10	
1:15		172	206	244	298	350	319	164	31	17		20	0	10	9	
1:30		130	146	158	170	198	227	142	34	18		20	0	6	6	
1:33																Sat.Stm.Off

TEST NO. 4

This test was made using a sample of King Coal from Carbon County, Utah, and was provided for this study by the Utah Fuel Company.

The time required for distillation was slightly over one hour, indicating, of course, that the coal was easily processed. No trouble was experienced in the removal of the processed fuel from the retort.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 4

Date January 8, 1934 Coal King

Size of Coal - 1½" to +3/4" Superheated Steam Temp. 650 °C

Coal and Residue

1. Weight of raw coal charged, pounds..... 45.75
2. Weight of residue from the retort, pounds..... 29.25
3. Loss in weight, pounds 16.50, percent of total 36.1, pounds per ton of raw coal.... 723
4. Weight of raw coal, pounds per cu. ft..... 41.5
5. Weight of residue, pounds per cu. ft..... 21.0
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture fairly dense - large surface cracks
   (c) hardness good

Gas

7. Totalgas generated, cubic feet..... 50.0
   Cubic feet per ton of raw coal..... 2185

Crude Oil

8. Weight of crude oil, pounds..... 6.54
   Pounds per ton of raw coal..... 286

Superheated Steam

9. Apparent weight of steam used, pounds..... 79
   Pounds per ton of raw coal..... 3450

Saturated Steam

10. Weight of saturated steam used, pounds..... 54
    Pounds per ton of raw coal..... 2360

PROXIMATE ANALYSIS OF COAL*

Moisture 5.3 Volatile Matter 42

Fixed Carbon 45.9 Ash 6.8

Sulphur .7

Source of Analysis:
Utah Fuel Company

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 4

Date January 8, 1934 Barometer 25.83 in. of Hg.

Coal King

Size of Coal -1 1/2 to +3/4 Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	45.75
Weight of residue from the retort, pounds	29.25
Weight of raw coal, pounds per cubic foot	41.5
Weight of residue, pounds per cubic foot	21.0
Final reading of gas meter No. I, cubic feet	63.4
Initial reading of gas meter No. I, cubic feet	13.4
Superheated steam:	
Final reading of condensate tank, pounds	71.0
Weight of water from Condensers No. 2 and 3	12.0
Initial reading of condensate tank, pounds	4.0
Saturated steam:	
Final reading of condensate tank, pounds	80.0
Initial reading of condensate tank, pounds	26.0
Weight of crude oil, pounds	6.54

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		7.5	9	9	9	9	9	56.5	21	13						
12:12																Sup.Stm.On
12:15	648	138	94	82	98	94	100	98	42	12		15	3.5	5.5		
12:30	652	428	288	188	147	103	103	94	55	13		16	4.5	6		Gas On At
12:45	652	508	436	357	295	228	198	103	32	15		17	6	7		12:25
1:00	654	550	498	425	394	339	298	130	31	15		18	7.5	7		
1:15	662	543	508	455	430	404	346	145	22	17		15	9	7		
1:20																Sup.Stm.Off
1:25		495	464	413	394	360	261									
1:28																Sat.Stm.On
1:30		474	469	427	408	382	343	121	23	15.5		20		9	10	
1:45		228	290	342	376	388	374	146	24	15		19		8	8	
2:00		121	142	174	201	229	253	173	41	15.5		20		8	8	
2:05		113	124	148	168	192	214	139	37	15.5		0		0	0	Gas Off At 1:55
																Sat.Stm.Off At 2:05
																When T. C. No.7 Read 224°C.

TEST NO. 5

This test was also made using King coal but it was furnished by the Western Fuel Company of Salt Lake City, a retail dealer for the United States Fuel Company who are owners of the King coal properties.

During the carbonizing process, the back pressure on the retort gradually increased, indicating that deformation of the coal lumps was taking place, and thereby reducing the area of the voids. No difficulty was experienced, however, in completing the distillation, with the result that the process was carried out in one hour and twenty-five minutes; an average length of time. Deformation of the lumps, under controlled conditions to improve the density of the product, is one important feature of the process.

The residue, or smokeless fuel, was easily removed from the retort by working a chain inserted in the center of the retort so as to be surrounded by lumps of coal. The residue was in most cases in the same form as the original lumps, showing little tendency for the lumps to fuse together or to disintegrate. It was found that some of the coal in the upper portion of the retort fused together due to the higher temperatures and more rapid heat-

ing conditions existing in that locality.

The product was hard, as was the raw coal, and contained very few deep-seated expansion cracks showing that a good homogeneous smokeless fule of fine grain texture can be produced from this particular coal.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 5

Date January 16, 1934 Coal King

Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C

Coal and Residue

1. Weight of raw coal charged, pounds..... 45.50
2. Weight of residue from the retort, pounds..... 29.75
3. Loss in weight, pounds 15.75, percent of total 34.6, pounds per ton of raw coal.... 692
4. Weight of raw coal, pounds per cu. ft..... 40.5
5. Weight of residue, pounds per cu. ft. 21.0
6. Physical properties of the residue:
   (a) color dull black
   (b) texture fine grain-small surface cracks present
   (c) hardness good

Gas

7. Total gas generated, cubic feet..... 56.34
   Cubic feet per ton of raw coal..... 2475

Crude Oil

8. Weight of crude oil, pounds..... 6.48
   Pounds per ton of raw coal..... 285

Superheated Steam

9. Apparent weight of steam used, pounds..... 89.0
   Pounds per ton of raw coal..... 3915

Saturated Steam

10. Weight of saturated steam used, pounds..... 61.5
    Pounds per ton of raw coal..... 2700

PROXIMATE ANALYSIS OF COAL*

Moisture	4.80	Volatile Matter	42.84
Fixed Carbon	45.98	Ash	6.38
		Sulphur	0.55

*Source of Analysis:
Western Fuel Company

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 5

Date January 16, 1934 Barometer 25.70 in. of Hg.

Coal King

Size of Coal -1 1/2" to + 3/4 Superheated Steam Temp. 650 C.

Weight of raw coal charged, pounds	45.5
Weight of residue from the retort, pounds	29.75
Weight of raw coal, pounds per cubic foot	40.5
Weight of residue, pounds per cubic foot	21.0
Final reading of gas meter No. I cubic feet	58.37
Initial reading of gas meter No. I cubic feet	02.03
Superheated steam:	
Final reading of condensate tank, pounds	82.0
Weight of water from Condensers No. 2 and 3	8.0
Initial reading of condensate tank, pounds	1.0
Saturated steam:	
Final reading of condensate tank, pounds	114.0
Initial reading of condensate tank, pounds	52.5
Weight of crude oil, pounds	6.48

Time	Thermocouple Readings - C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5'	6	7	8	9	10		1	2	3	4	
	654	19	19	19	21	21	15	31	21	16						
2:25																Sup.Stm.On.
2:30	650	171	97	84	100	96	103	94	36	14		20	6	6		
2;45	650	436	376	244	194	139	113	101	51	17		21	9¾	9		
3:00	659	500	445	377	330	252	198	108	31	16		15	9	11		
3:15	654	507	460	410	380	309	250	99	27	16		11	5	4		
3:30	659	514	492	448	444	396	342	106	28	13		17	9	4		
3:50																Sup.Stm.Off
																T.C.No. 7
																362 °C.
3:55																Sat. Stm.On
4:00		418	458	434	430	400	348	113	28	17		20	-	5	9	
4:45																Sat. Stm.Off
																T.C.No. 7
																204 °C.

TESTS NO'S. 6 AND 7

This test and the following one were made using Aberdeen coal mined at Kenilworth in Carbon County, Utah. The Independent Coal and Coke Company and its retailer, the Citizens Coal Company, willingly furnished the coal used for these tests and others.

This coal was recognized as being especially well suited to the manner of treatment.

The time required for the distillation was approximately 1¼ hours. With the aid of the chain, which is used, as aforementioned to regulate the pressure or weight of the coal lumps, the smokeless fuel was easily removed from the retort.

The partly cooled, dry quenched, residue from Test No. 7 was allowed to remain in a pile on the floor over night. Because this semi-coke produced by low-temperature carbonization is a highly activated form of carbon, the pile took fire and only a bed of ashes remained by the next day. Consequently, the smokeless fuel could not be weighed.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 6

Date January 31, 1934 Coal Aberdeen
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 45.25
2. Weight of residue from the retort, pounds..... 30.75
3. Loss in weight, pounds 14.50, percent of total 32.1, pounds per ton of raw coal..... 642
4. Weight of raw coal, pounds per cu. ft..... 40.25
5. Weight of residue, pounds per cu. ft..... 22.50
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture fine, very few surface cracks
   (c) hardness good

Gas

7. Total gas generated, cubic feet..... 73.7
   Cubic feet per ton of raw coal..... 3260

Crude Oil

8. Weight of ~~wet~~ crude oil, pounds..... 6.41
   Pounds per ton of raw coal..... 284

Superheated Steam

9. Apparent weight of steam used, pounds..... 84.0
   Pounds per ton of raw coal..... 3710

Saturated Steam

10. Weight of saturated steam used, pounds..... 57.0
    Pounds per ton of raw coal..... 2520

PROXIMATE ANALYSIS OF COAL*

Moisture	2.42	Volatile Matter	40.95
Fixed Carbon	51.64	Ash	4.99
Sulphur	.234	B.T.U.	13,230

*Source of Analysis:
Citizens Coal Co.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 6

Date January 31, 1934 Barometer 26.0 in. of Hg.
Coal Aberdeen
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	45.25
Weight of residue from the retort, pounds	30.75
Weight of raw coal, pounds per cubic foot	40.25
Weight of residue, pounds per cubic foot	22.50
Final reading of gas meter No. I, cubic feet	114.90
Initial reading of gas meter No. I, cubic feet	41.20
Superheated steam:	
Final reading of condensate tank, pounds	76.50
Weight of water from Condensers No. 2 and 3	15.0
Initial reading of condensate tank, pounds	7.50
Saturated steam:	
Final reading of condensate tank, pounds	96.0
Initial reading of condensate tank, pounds	39.0
Weight of crude oil, pounds	6.41

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		15	15	15	15	15	13									
1:26																Sup.Stm.On
1:30	645	93	91	77	96	92	100	96	24	12		12	2	2		Gas On 1:35
1:45	650	391	242	115	99	96	99	94	48	13		14	5	2		
2:00	650	492	420	276	214	151	106	90	29	15		14	5.5	2		
2:15	645	534	466	405	355	266	181	95	19	19		15	7.5	3		
2:30	664	556	504	458	444	374	270	118	40	19		15	7.5	2		
2:45	650	560	528	481	474	431	356	140	29	18		15	5.5	0		
2:50																Sup.Stm.Off
																T.C.No. 7
3:00															10	366 °C.
3:15		160	192	235	272	334	355	232	37	22		-	-	2	10	Sat.Stm.On
																At 3:00
3:28																Sat.Stm.Off
																T.C.No. 7
																206 °C.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 7

Date February 3, 1934 Coal Aberdeen
Size of Coal -1 5/8" to #3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 45.50
2. Weight of residue from the retort, pounds.....
3. Loss in weight, pounds_____,percent of total_____, pounds per ton of raw coal.....
4. Weight of raw coal, pounds per cu. ft..... 40.5
5. Weight of residue, pounds per cu. ft.....
6. Physical properties of the residue:
   (a) color Black, dull luster
   (b) texture Fine. Very few surface cracks
   (c) hardness Good.

Gas

7. Total gas generated, cubic feet..... 65.65
   Cubic feet per ton of raw coal..... 2885

Crude Oil

8. Weight of crude oil, pounds..... 5.9
   Pounds per ton of raw coal..... 259.0 **

Superheated Steam

9. Apparent weight of steam used, pounds..... 79.0
   Pounds per ton of raw coal..... 3470

Saturated Steam

10. Weight of saturated steam used, pounds..... 62.5
    Pounds per ton of raw coal..... 2750

** Average of 7 tests.

PROXIMATE ANALYSIS OF COAL*

Moisture	2.42	Volatile Matter	40.95
Fixed Carbon	51.64	Ash	4.99
Sulphur	0.234	Btu	13,230

* Source of Analysis:

Citizens Coal Company.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 7

Date February 3, 1934 Barometer 25.45 in. of Hg.

Coal Aberdeen

Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds..... 45.50
Weight of residue from the retort, pounds..... ---
Weight of raw coal, pounds per cubic foot..... 40.5
Weight of residue, pounds per cubic foot..... ---

Final reading of gas meter No. I, cubic feet..... 123.90
Initial reading of gas meter No. I, cubic feet..... 58.25

Superheated steam:
Final reading of condensate tank, pounds..... 64.5
Weight of water from Condensers No. 2 and 3..... 18.5
Initial reading of condensate tank, pounds..... 4.0

Saturated steam:
Final reading of condensate tank, pounds..... 87.00
Initial reading of condensate tank, pounds..... 24.50

Weight of crude oil, pounds..... 5.9

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		155	13	16	16	16	13									
1:13																Sup.Stm. On
1:24																Gas On
1:30	650	412	234	118	97	94	98	90	20	17		16	6.5	1		
1:45	650	532	452	360	282	202	134	94	21	19		19	11	1		
2:00	652	544	476	410	400	291	188	94	21	18		16	9	0		
2:15	654	552	488	448	433	382	298	118	29	17		18	13	0		
2:40	654	554	490	460	460	422	370									Sup.Stm.Off
2:50															10	Sat.Stm.On
3:14																Gas Off
3:25		120					212									Sat.Stm.Off

TEST NO. 8

This test was made on Standard Coal from Carbon County, Utah. The Standard Fuel Company furnished the sample used.

The time required for carbonization was about 1 3/4 hours, which indicates that the fusing properties of this coal are on par with those of the coal from the Castlegate No. 2 mine, "D" Seam.

A smokeless fuel of good physical properties was obtained, but required a little more work in removing the agglomerated mass from the retort than did some of the coals such as King or Aberdeen.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 8

Date January 30, 1934 Coal Standard
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 43.75
2. Weight of residue from the retort, pounds..... 30.00
3. Loss in weight, pounds 13.75, percent of total 31.5, pounds per ton of raw coal..... 630
4. Weight of raw coal, pounds per cu. ft..... 39.25
5. Weight of residue, pounds per cu. ft..... 20.00
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture very fine, no surface cracks, fused
   (c) hardness good

Gas

7. Total gas generated, cubic feet..... 58.88
   Cubic feet per ton of raw coal..... 2690

Crude Oil

8. Weight of ~~wet~~ crude oil, pounds..... 6.0
   Pounds per ton of raw coal..... 275

Superheated Steam

9. Apparent weight of steam used, pounds..... 77.0
   Pounds per ton of raw coal..... 3520

Saturated Steam

10. Weight of saturated steam used, pounds..... 58.0
    Pounds per ton of raw coal..... 2655

PROXIMATE ANALYSIS OF COAL*

Moisture	4.1	Volatile Matter	44.0
Fixed Carbon	47.5	Ash	4.4
Sulphur	0.4	B.T.U.	13,230

*Source of Analysis:
Standard Fuel Co.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 8

Date January 30, 1934 Barometer 25.54 in. of Hg.
Coal Standard
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds..... 43.75
Weight of residue from the retort, pounds..... 30.00
Weight of raw coal, pounds per cubic foot..... 39.25
Weight of residue, pounds per cubic foot..... 20.00

Final reading of gas meter No. I, cubic feet..... 139.26
Initial reading of gas meter No. I, cubic feet..... 80.38

Superheated steam:
Final reading of condensate tank, pounds..... 72.5
Weight of water from Condensers No. 2 and 3..... 12.0
Initial reading of condensate tank, pounds..... 7.5

Saturated steam:
Final reading of condensate tank, pounds..... 94.0
Initial reading of condensate tank, pounds..... 36.0

Weight of crude oil, pounds..... 6.0

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		10.5	10.5	10.5	13.5	13.5	12									
1:17																Sup.Stm.On
1:30	642	412	262	144	118	100	106	93	23	18		15	9	1		
1:45	640	419	366	250	193	137	109	93	23	17		15	9	2		
2:00	654	518	414	368	291	216	158	91	44	17						
2:30	669	478	400	358	306	232	168	95	30	18		20	14	2		
2:50	674	560	504	450	424	410	310	99	42	18		20	13	2		
3:05																Sup.Stm.Off
																T.C.No.7
																348 °C.
3:12																Sat.Stm.On
3:53																Gas Off
4:18																Sat.Stm.Off
																T.C.No.7
																218 °C.

TEST NO. 9

The Anchor Lumber and Coal Company supplied the test sample of coal from the Sevier Valley Coal Company mine in Salina Canyon, Sevier County, Utah.

Only 50 minutes were required for the distillation, which was lower than any of the preceding distilling periods.

The residue fell freely from the retort since no agglomeration of the lumps took place. However, the smokeless fuel disintegrated into smaller pieces than the original raw coal lumps. This phenomenon is characteristic of the behavior of the subbituminous coals when subjected to this treatment.

The writer later learned that the sample used for this test was obtained from a coal pile which had been subjected to the weathering agents of the atmosphere for a considerable time. Consequently, a fresh sample was obtained and distilled as Preliminary Test No. 19.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 9

Date February 6, 1934 Coal Sevier Valley Coal Mine.
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 45.5
2. Weight of residue from the retort, pounds..... 28.0
3. Loss in weight, pounds 17.5, percent of total 38.4, pounds per ton of raw coal..... 769
4. Weight of raw coal, pounds per cu. ft..... 41.5
5. Weight of residue, pounds per cu. ft..... 30.5
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture fine, but large cracks thru lumps
   (c) hardness hard

Gas

7. Total gas generated, cubic feet..... 62.8
   Cubic feet per ton of raw coal..... 2760

Crude Oil

8. Weight of ~~wet~~ crude oil, pounds..... 6.25
   Pounds per ton of raw coal..... 275

Superheated Steam

9. Apparent weight of steam used, pounds..... 74.
   Pounds per ton of raw coal..... 3250

Saturated Steam

10. Weight of saturated steam used, pounds..... 55.5
    Pounds per ton of raw coal..... 2440

PROXIMATE ANALYSIS OF COAL*

Moisture	10.0	Volatile Matter	37.6
Fixed Carbon	48.2	Ash	4.2
Sulphur	0.5	B.T.U.	11,860

*Source of Analysis:
U.S.B.M. T.P. 345 for Sevier Valley Coal Mining Co.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 9

Date February 6, 1934 Barometer 25.43 in. Hg.

Coal Sevier Valley

Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	45.5
Weight of residue from the retort, pounds	28.0
Weight of raw coal, pounds per cubic foot	41.5
Weight of residue, pounds per cubic foot	30.5
Final reading of gas meter No. I, cubic feet	88.4
Initial reading of gas meter No. I, cubic feet	25.6
Superheated steam:	
Final reading of condensate tank, pounds	73.5
Weight of water from Condensers No. 2 and 3	6.0
Initial reading of condensate tank, pounds	5.5
Saturated steam:	
Final reading of condensate tank, pounds	104.0
Initial reading of condensate tank, pounds	48.5
Weight of crude oil, pounds	6.25

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		16	16	16	17.5	17.5	17.5									
2:20	650															Sup.Stm.On
2:29																Gas On
2:30	638	358	210	108	103	102	106	98	54	20		20	7	1		
2:50	644	550	510	424	398	306	258	111	83	20						
3:00	671	568	532	478	471	403	372	146	59	21						
3:10																Sup. Stm. Off
3:15																Sat. Stm. On
3:26																T.C. No. 7
																448 °C.
																(Maximum)
3:42																Sat. Stm. Off
																T.C. No. 7
																212 °C

TEST NO. 10

This test was made using coal from Rilda Canyon in Emery County, Utah. Mining of coal in this locality is not practiced on a large scale at the present time.

The processed coal contained an appreciable amount of resin with rock inclusions in layers about 1/4 inch thick; but the raw coal was observed to be very hard. The raw coal had to be broken up into sizes ranging from 2 inches to 3/4 inch in order to charge it in the retort.

No new conditions of operation were encountered for no excessive retort back pressure developed and the distillation was made in one hour as is the case in most instances.

The smokeless fuel or residue from the retort had a fine texture but was quite friable.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 10

Date January 20, 1934 Coal from Rilda Canyon in Emery Co., Utah
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 39.5
2. Weight of residue from the retort, pounds..... 25.25
3. Loss in weight, pounds 14.25, percent of total 36.1, pounds per ton of raw coal..... 723
4. Weight of raw coal, pounds per cu. ft..... 37.5
5. Weight of residue, pounds per cu. ft..... 19.5
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture fairly fine, few large surface cracks
   (c) hardness fair, large lumps(+1 1/2") break up easily

Gas

7. Total gas generated, cubic feet..... 42.18
   Cubic feet per ton of raw coal..... 2135

Crude Oil

8. Weight of ~~wet~~ crude oil, pounds..... 6.3
   Pounds per ton of raw coal..... 319

Superheated Steam

9. Apparent weight of steam used, pounds..... 77.0
   Pounds per ton of raw coal..... 3900

Saturated Steam

10. Weight of saturated steam used, pounds..... 50.5
    Pounds per ton of raw coal..... 2555

PROXIMATE ANALYSIS OF COAL*

Moisture _____ Volatile Matter _____
Fixed Carbon _____ Ash _____
Sulphur _____

*Source of Analysis:

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 10

Date January 20, 1934 Barometer - in. of Hg.
Coal Rilda Canyon
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds..... 39.5
Weight of residue from the retort, pounds..... 25.25
Weight of raw coal, pounds per cubic foot..... 37.5
Weight of residue, pounds per cubic foot..... 19.5

Final reading of gas meter No. I cubic feet..... 102.68
Initial reading of gas meter No. I cubic feet..... 60.5

Superheated steam:
Final reading of condensate tank, pounds..... 80.0
Weight of water from Condensers No. 2 and 3..... 6.0
Initial reading of condensate tank, pounds..... 9.0

Saturated steam:
Final reading of condensate tank, pounds..... 81.5
Initial reading of condensate tank, pounds..... 31.0
Weight of crude oil, pounds..... 6.3

Time	Thermocouple Readings -°C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		24	22	22	22	22	17	44	16	11						
10:25																Sup.Stm.On
10:30	650	191	103	88	101	101	101	98	21	13		16	4.5	3		
10:45	648	436	368	267	229	173	148	93	32	14		18	6	4		Gas On
11:00	654	500	450	399	354	286	252	102	33	15		19	7.5	5		
11:15	657	545	500	450	443	394	346	152	42	15.5		19	8	2		
11:27																Sup.Stm.Off
																T.C.No. 7
																414 °C.
11:37															10	
11:45		306	375	399	420	394	366	151	34	17		20	-	-	10	
12:00		161	188	224	255	292	300	176	31	14		20	-	-	10	Gas Off
12:12																Sat. Stm. Off
																T.C.No. 7
																218 °C.

TEST NO. 11

The coal used was supplied by the Weber Coal Company of Coalville, Utah. The sample carbonized came from this Company's Grass Creek mine near Coalville.

No trouble was experienced in the distillation of the coal charge. The back pressure on the retort remained practically constant during the entire run, indicating that no fusing was taking place. This was proven to be the case when the residue was removed from the retort with no difficulty.

A coke having about the same general physical characteristics of the raw coal waspproduced. The fuel had bright, lustrous, smooth surfaces and, according to Mr. Vernon H. Cato of the Wever Coal Company, was no softer than the raw coal after it has been subjected to the atmosphere for a few weeks. A screen analysis of the smokeless fuel is given below:

Size	Weight	Per cent of total
1½" to ½"	14.0 lbs.	51.4
½" to ¼"	9.5 lbs.	34.8
below ¼"	3.75 lbs.	13.8

The product made in this test was better than that made from the Weber coal (see test No. 12) in that it was not as friable and came out of the retort in larger lumps.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 11

Date January 10, 1934 Coal Grass Creek- Coalville
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 49.25
2. Weight of residue from the retort, pounds..... 27.25
3. Loss in weight, pounds 22, percent of total 44.6, pounds per ton of raw coal..... 894
4. Weight of raw coal, pounds per cu. ft..... 40.5
5. Weight of residue, pounds per cu. ft..... 36.4
6. Physical properties of the residue:
   (a) color bright luster, black
   (b) texture mass finely cracked throughout
   (c) hardness soft, friable

Gas

7. Total gas generated, cubic feet..... 76.4
   Cubic feet per ton of raw coal..... 3100

Crude Oil

8. Weight of crude oil, pounds..... 4.95
   Pounds per ton of raw coal..... 201

Superheated Steam

9. Apparent weight of steam used, pounds..... 102.
   Pounds per ton of raw coal..... 4140

Saturated Steam

10. Weight of saturated steam used, pounds..... 47.
    Pounds per ton of raw coal..... 1910

PROXIMATE ANALYSIS OF COAL*

Moisture	16.0	Volatile Matter	36.9
Fixed Carbon	43.3	Ash	3.8
Sulphur	1.7	Calorific Value	10,680 B.T.U.

*Source of Analysis:
U.S.B.M. Tech. Paper 345

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 11

Date January 10, 1934 Barometer 25.42 in. of Hg.
Coal Grass Creek from Coalville
Size of Coal Stoker sized to 3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	49.25
Weight of residue from the retort, pounds	27.25
Weight of raw coal, pounds per cubic foot	40.5
Weight of residue, pounds per cubic foot	36.4
Final reading of gas meter No. I, cubic feet	100.2
Initial reading of gas meter No. I, cubic feet	23.80
Superheated steam:	
Final reading of condensate tank, pounds	91.0
Weight of water from Condensers No. 2 and 3	15.0
Initial reading of condensate tank, pounds	4.0
Saturated steam:	
Final reading of condensate tank, pounds	81.5
Initial reading of condensate tank, pounds	34.5
Weight of crude oil, pounds	4.95

Time	Thermocouple Readings, °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		22	20	20	20	20	11	87	19	13						
12:05	643															Sup.Stm.On
12:11																Gas On
12:15	652	246	106	88	96	96	96	93	60	13		15	4.5	4		
12:30	650	422	310	167	111	96	96	94	82	15		15	4.5	5		
12:45	650	516	460	360	290	181	115	100	62	13		15	4.5	5.5		
1:00	652	508	502	445	416	328	198	102	43	15		15	5	6		
1:15	650	512	512	464	462	408	294	105	41	15.5		15	5	6.5		
1:25																Sup.Stm.Off
																T.C.No. 7
																392 °C.
1:45		198	188	229	283	379	408	209	42	15.5		20	0	2	10	Sat.Stm.On
																At 1:34
1:53																Gas Off
1:58																Sat.Stm.Off
																T.C.No. 7
																220 °C.

TEST NO. 12

The coal used was supplied by the Weber Coal Company of Coalville, Utah. The sample carbonized came from the Weber mine and was prepared by screening a sack of the company's "Stoker" coal over a 3/4-inch screen, thereby providing lumps sized from 2 inch to 3/4-inch.

No new conditions were experienced in the distillation of the coal charge. Back pressure on the retort did not vary during the entire run, indicating that no fusing was taking place. The residue was removed from the retort with no tendency to arch.

The treated lumps had a bright luster and smooth surfaces. Practically all of the large lumps had been broken up into small pieces, so that the entire charge as it came from the retort could easily have passed a 1-inch screen.

As produced from this run, it is doubtful if the smokeless fuel would have widespread polularity as a domestic fuel, since it comprises a mixture of small sizes and the lumps break up into small pieces which could not be burned without suitable furnace grates or stokers.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 12

Date January 15, 1934 Coal Weber Mine from Summit Co., Utah
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 49.5
2. Weight of residue from the retort, pounds..... 28.0
3. Loss in weight, pounds 21.5, percent of total 43.5, pounds per ton of raw coal..... 870
4. Weight of raw coal, pounds per cu. ft..... 40.0
5. Weight of residue, pounds per cu. ft..... 35.4
6. Physical properties of the residue:
   (a) color bright black
   (b) texture fine, deep seated cracks present
   (c) hardness very friable, crushes easily between fingers

Gas

7. Total gas generated, cubic feet..... 83.0
   Cubic feet per ton of raw coal..... 3350

Crude Oil

8. Weight of crude oil, pounds..... 4.97
   Pounds per ton of raw coal..... 201

Superheated Steam

9. Apparent weight of steam used, pounds..... 92.0
   Pounds per ton of raw coal..... 3720

Saturated Steam

10. Weight of saturated steam used, pounds..... 48.5
    Pounds per ton of raw coal..... 1960

PROXIMATE ANALYSIS OF COAL*

Moisture	13.7	Volatile Matter	38.3
Fixed Carbon	43.6	Ash	4.4
Sulphur	1.5	Calorific Value	10,870 B.T.U.

*Source of Analysis:
U.S.B.M. Tech. Paper 345

LOW-TEMPERATURE CARBONIZATION PLANT

University Of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 12

Date January 15, 1934 Barometer 25.65 in. of Hg.
Coal Weber Coal from Coalville.
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	49.5
Weight of residue from the retort, pounds	28.0
Weight of raw coal, pounds per cubic foot	40.0
Weight of residue, pounds per cubic foot	35.4
Final reading of gas meter No. I, cubic feet	108.0
Initial reading of gas meter No. I, cubic feet	25.0
Superheated steam:	
Final reading of condensate tank, pounds	80.5
Weight of water from Condensers No. 2 and 3	18.0
Initial reading of condensate tank, pounds	6.5
Saturated steam:	
Final reading of condensate tank, pounds	93.0
Initial reading of condensate tank, pounds	44.5
Weight of crude oil, pounds	4.97

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		11	12.5	12.5	12.5	12.5	12.5	93	19.5	17.5						
12:40																Sup.Stm.On
12:45	650	144	96	89	100	99	101	95	42	17		18	6	5		
12:50																Gas On
1:04	650	489	366	203	138	103	101	95	61	19.5		18	6	5		
1:15	640	536	480	361	301	181	114	98	48	16		18	6	5		
1:30	659	536	516	453	448	348	272	102	36	16		18	8	6		
1:45																Sup.Stm. Off T.C.No.7 396 °C.
1:50																Sat.Stm.On
2:00		252	238	296	388	450	450	192	31	17		20	0	2	10	
2:15		154	154	168	178	214	230	174	30	15.5		20	0	2	10	
2:20																Sat.Stm.Off T.C.No.7 218 °C.

TEST NO. 13

This test was made on the coal from the Weber Mine at Coalville. Since the residue from a previous run (Test No. 12) was very friable and hence, in small sizes, this test was made as an attempt to produce a smokeless fuel containing larger size lumps.

It was recognized that if heat was supplied at a slow rate and while maintaining a high vapor pressure in the retort, the excessive moisture in this subbituminous coal would be vaporized gradually from all portions of the lumps, so that the coal would not be cracked into several pieces. Excessive cracking takes place when the moisture is quickly evaporated from the surfaces of the lumps.

Therefore, the coal charge was preheated slowly for 50 minutes with superheated steam which attained a final temperature of 275° C., and then distilled with 650° C. steam for another 50 minutes.

As far as this test was concerned, the preheating produced no change in the physical characteristics of the residue. The coke appeared to be identical with that obtained without preheating as in Test No. 12.

On April 20, 1934, a fresh sample of Weber coal was obtained at the mine, and was processed four days later. This time, the superheated steam temperature was raised gradually so that 3 hours and 45 minutes were required for the distillation. The maximum steam temperature was 600° C. and the maximum temperature of the vapors leaving the retort was 400° C. With time allowed for dry-quenching or cooling down of the coal charge, and also for the charging of the retort, about five distillations could be made per retort per 24 hours.

A screen analysis of the smokeless fuel made from this particular test is given below:

Size	Weight	Per cent of Total
15/8" to 3/4"	13.0	44.8
3/4" to 1/2"	6.0	20.7
1/2" to 1/4"	5.75	19.8
below 1/4"	4.25	14.7

It is evident, therefore, that a comparatively slow heating and distilling of this particular subbituminous coal will give a product of which only 55 per cent broke up into sizes smaller than the minimum size of coal charged.

Many lumps were very large and appeared to have undergone no change in shape whatever.

From the above processing results, the writer believes that other subbituminous and low rank coals can be treated by this method so that suitable domestic lump products can be produced.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 13

Date January 26, 1934 Coal Weber Coal- Coalville
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 46.75
2. Weight of residue from the retort, pounds..... 28.0
3. Loss in weight, pounds 18.75, percent of total 40, pounds per ton of raw coal..... 800
4. Weight of raw coal, pounds per cu. ft..... 40.25
5. Weight of residue, pounds per cu. ft..... 37.40
6. Physical properties of the residue:
   (a) color black, bright luster
   (b) texture finely cracked
   (c) hardness soft, very friable

Gas

7. Total gas generated, cubic feet..... 73.29
   Cubic feet per ton of raw coal..... 3135

Crude Oil

8. Weight of crude oil, pounds..... 4.35
   Pounds per ton of raw coal..... 186

Superheated Steam **

9. Weight of steam used, pounds..... 62.75
   Pounds per ton of raw coal..... 2685

Saturated Steam

10. Weight of saturated steam used, pounds..... 54.5
    Pounds per ton of raw coal..... 2330

PROXIMATE ANALYSIS OF COAL*

Moisture	13.7	Volatile Matter	38.3
Fixed Carbon	43.6	Ash	4.4
Sulphur	1.5	Calorific Value	10,870 B.T.U.

*Source of Analysis:
U.S.B.M. Tech. Paper 345

**For Preheating Period:
Apparent weight of steam used, pounds..... 98.0
Pounds per ton of raw coal..... 4180.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 13

Date January 26, 1934 Barometer 25.62 in. of Hg.
Coal Weber Coal from Coalville
Size of Coal -2" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	46.75
Weight of residue from the retort, pounds	28.0
Weight of raw coal, pounds per cubic foot	40.25
Weight of residue, pounds per cubic foot	37.4
Final reading of gas meter No. I, cubic feet	78.79
Initial reading of gas meter No. I, cubic feet	5.5
Superheated steam:	
Final reading of condensate tank, pounds	61.0
Weight of water from Condensers No. 2 and 3	9.75
Initial reading of condensate tank, pounds	8.0
Saturated steam:	
Final reading of condensate tank, pounds	94.0
Initial reading of condensate tank, pounds	39.5
Weight of crude oil, pounds	4.35

Time	Thermocouple Readings - °C.										Ave.	Stm.Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10'		1	2	3	4	
	275	10	10	10	12	12	12									
11:53												20	6	2		Preheat.
12:00	278	135	103	90	104	102	105	96				20	6.5	2		Stm. On
12:05	275	171	127	92	104	102	105	96				20	6.5	2		
12:10	272	192	149	100	104	102	105	96				20	6.5	2		
12:15	275	206	170	114	107	103	103	95				20	6.5	2		
12:20	275	217	189	136	121	103	103	95				20	7.5	2		
12:25	272	221	201	150	135	108	103	95				20	7.5	2		
12:30	277	226	209	165	151	116	104	95				20	7.5	2		
12:35	275	229	215	175	167	127	112	95				20	7.5	2		
12:40	272	234	221	184	181	142	120	95				20	7.5	2		
12:43																Preheat Stm.Off
1:40		162	159	132	117	95	50	89								
1:45																Sup.Stm.On
1:53																Gas On.
2:00	650	469	377	275	251	191	151	100	61	18		17	5.5	4		
2:15	650	534	470	394	373	299	216	96	77	17		17	6.5	3		
2:30	660	536	518	474	460	409	474									
2:33																Sup.Stm.Off
2:42																Sat.Stm.On
3:10							184									
3:11																Sat.Stm.Off

*Steam for preheating period: Final cond. tank reading - 103 lbs.
Initial

TEST NO. 14

This test was made using Peacock coal from Rock Springs, Wyoming, which was furnished by the Western Fuel Company of Salt Lake City. The retort was charged with a sample obtained by screening one-hundred pounds of pea coal over a 3/4-inch screen, thereby, providing lumps sized from 1 and 5/8 inch to 3/4 inch.

During the carbonizing process, the back pressure on the retort gradually increased, reaching a maximum of 15 lb. per sq. inch gauge about one hour after the test was started.

The residue, or smokeless fuel, was quite easily removed from the retort. The coke was in most cases in the same form as the original lumps of coal showing little tendency for the lumps to fuse together or disintegrate. However, the coke had large surface cracks showing that swelling had taken place during the carbonizing period which had the effect of building up the back pressure.

The product was hard and dense, even though there were large surface cracks present. Based on the observed physical properties, it can be concluded that a good smokeless fuel can be made from this coal.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 14

Date January 9, 1934 Coal Peacock Coal from Rock Springs
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 45.75
2. Weight of residue from the retort, pounds..... 29.50
3. Loss in weight, pounds 16.25, percent of total 35.60, pounds per ton of raw coal..... 712
4. Weight of raw coal, pounds per cu. ft..... 40.5
5. Weight of residue, pounds per cu. ft..... 19.5
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture dense, large surface cracks
   (c) hardness good

Gas

7. Total gas generated, cubic feet..... 58.07
   Cubic feet per ton of raw coal..... 2540

Crude Oil

8. Weight of ~~wet~~ crude oil, pounds..... 5.07
   Pounds per ton of raw coal..... 221

Superheated Steam

9. Apparent weight of steam used, pounds..... 91.5
   Pounds per ton of raw coal..... 4000

Saturated Steam

10. Weight of saturated steam used, pounds..... 54.0
    Pounds per ton of raw coal..... 2360

PROXIMATE ANALYSIS OF COAL*

Moisture	6.3	Volatile Matter	38.98
Fixed Carbon	51.07	Ash	3.65
	Sulphur 1.00		

*Source of Analysis:
Western Fuel Co.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 14

Date January 9,1934 Barometer 25.72 in. of Hg.
Coal Rock Springs
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds..... 45.75
Weight of residue from the retort, pounds..... 29.50
Weight of raw coal, pounds per cubic foot..... 40.5
Weight of residue, pounds per cubic foot..... 19.5

Final reading of gas meter No. I, cubic feet..... 123.70
Initial reading of gas meter No. I, cubic feet..... 65.63

Superheated steam:
Final reading of cindensate tank, pounds..... 82.0
Weight of water from Condensers No. 2 and 3..... 15.5
Initial reading of condensate tank, pounds..... 6.0

Saturated steam:
Final reading of condensate tank, pounds..... 84.0
Initial reading of condensate tank, pounds..... 30.0

Weight of crude oil, pounds..... 5.07

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		185	19	19	19	16	11	29	20	12						
11:02	654	38	38	22	48	31	98	82	40	12		20	2.5	4		Sup.Stm.On
11:15	650	396	230	120	101	99	104	99	83	16		21	7.5	9		Gas On At 11:12
11:30	660	490	412	348	294	206	132	104	24	15		16	8	7.5		
11:45	645	514	460	392	390	304	229	108	54	16						
12:00	650	544	508	460	446	406	381	164	78	16		17	7	10		
12:10																Sup.Stm.Off
12:15		482	458	418	404	368	258	109	31	13		20		0	0	
12:18																Sat.Stm.On
12:22												20		7	9.5	
12:30		270	373	404	436	426	411	172	30	14		20		10	6.5	
12:43																Gas Off
12:45		148	170	196	238	268	284	179	27	13		20		5.5	7	
12:55		130	148	161	181	201	196	126	23	12						Sat.Stm.Off

TEST NO. 15

This test was conducted on a sample of coal from the Willow Creek, or No. 5 bed in the Kemmerer field, of Wyoming. The Kemmerer Coal Company furnished the coal sample.

Coal from this field is known as the best grade bituminous coal within the State of Wyoming, and is mined from a seam of from 60 to 70 inches thickness.

Considerable difficulty was experienced in processing this coal. From inspection of the laboratory data sheet, it will be seen that even after 2 hours and 45 minutes, the temperature of the volatiles leaving the retort was only 238° C. A minimum temperature of 360° C. is required before the distillation is complete. The excess time required was caused by the unusual fusing and swelling of the coal lumps which decreased the area of the channels through which the superheated steam must flow. The fact that the residue was hard to remove from the retort is further evidence of the swelling and the accompanying fusing of the coal lumps which took place. In this test the distillation was not complete so that the yields of gas and oil are lower than they would be if distillation had been consummated.

From this preliminary investigation it may be concluded that this coal would be relatively expensive to process in commercial quantities, since more time is required and, therefore, a smaller daily production would be obtained. This coal, undoubtedly can be prevented from fusing and swelling by pre-treating methods of Parr and Wisner, as herein described, which have been applied to Eastern Coking fusing coals. Obviously, this pre-treatment would add to the cost, but the time required for distilling would be materially decreased.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 15

Date February 2, 1934 Coal Kemmerer No. 5
Size of Coal -1 5/8" to + 3/4" Superheated Steam Temp. 650 °C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 46.25
2. Weight of residue from the retort, pounds..... 35.0
3. Loss in weight, pounds 11.25, percent of total 24.3, pounds per ton of raw coal..... 486
4. Weight of raw coal, pounds per cu. ft..... 40.5
5. Weight of residue, pounds per cu. ft..... 23.5
6. Physical properties of the residue:
   (a) color black, dull luster
   (b) texture porus
   (c) hardness fair, brittle

Gas

7. Total gas generated, cubic feet..... 38.19
   Cubic feet per ton of raw coal..... 1650

Crude Oil

8. Weight of crude oil, pounds..... 4.85
   Pounds per ton of raw coal..... 210

Superheated Steam

9. Apparent weight of steam used, pounds..... 77.5
   Pounds per ton of raw coal..... 3350

Saturated Steam

10. Weight of saturated steam used, pounds..... 62.5
    Pounds per ton of raw coal..... 2700

PROXIMATE ANALYSIS OF COAL *

Moisture	3.8	Volatile Matter	37.1
Fixed Carbon	52.9	Ash	6.2
	Sulphur	0.9	

* Source of Analysis:
U.S.B.M. Tech. Paper 484

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 15

Date February 2, 1934 Barometer _____ in. of Hg.
Coal Kemmerer No. 5
Size of Coal -1 5/8" to +3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds..... 46.25
Weight of residue from the retort, pounds..... 35.0
Weight of raw coal, pounds per cubic foot..... 40.5
Weight of residue, pounds per cubic foot..... 23.5

Final reading of gas meter No. I, cubic feet..... 56.19
Initial reading of gas meter No. I, cubic feet..... 18.0

Superheated steam:
Final reading of condensate tank, pounds..... 81.0
Weight of water from Condensers No. 2 and 3..... 8.0
Initial reading of condensate tank, pounds..... 12.5

Saturated steam:
Final reading of condensate tank, pounds..... 110.0
Initial reading of condensate tank, pounds..... 47.5

Weight of crude oil, pounds..... 4.85

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
12:10	648	13	13	13	13	13	13	14	16	13						
12:15																Sup. Stm.On
12:25																Gas On
12:30	650	422	334	197	161	113	102	96	28	15		20	10	1		
12:45	648	471	380	303	233	161	123	95	21	15		15	10	1		
1:00	652	436	357	298	240	162	119	92	33	17		15	9	1		
1:15	650	442	358	308	264	182	128	91	37	15		14	10	1		
1:30	659	506	419	361	324	253	165	96	36	16		22	14	1		
1:45	607	492	436	377	377	312	193	93	26	17		19	14	1		
2:00	626	460	418	363	358	309	188	95	34	16						
2:15	666	455	412	358	348	303	205	93	38	17		17	20	1		
2:30	662	450	408	360	349	306	219	92	35	15		19	15	1		
2:45	659	482	422	375	366	324	225	96	39	17		24	20	1		
3:00						344	238									Sup.Stm.Off
3:10															15	Sat.Stm. On
3:37										37						T.C.No. 7 332 °C. (Maximum)
3:45																Gas Off
4:00																Sat.Stm.Off T.C.No. 7 220 °C.

TEST NO'S. 16 AND 17

With the idea of using a good bituminous coal from Wyoming which would process more easily than the coal from the No. 5 bed (Test No. 15), samples from the Susie Mine near Kemmerer were obtained. These samples were again furnished by the Kemmerer Coal Company.

Because the pressure-regulating chain inside the retort, by accident, did not extend into the lower 18 inches of the retort, the coal there fused together so that 1 hour and 24 minutes were required to distill the last 18 inches.

As a direct result of this, the same coal was again carbonized, but the lower 4 feet of the retort contained coal sized from 1½ inch to 3/4 inch, and the upper 4 feet was filled with coal sized from 3/4 inch to ½ inch. This selective charging of the retort was used in order to take advantage of the weight of the column of coal above each coal lump so that a dense smokeless fuel could be made, and also so that the smaller lumps under the least coal pressure could be processed. The distilling of this charge with the chain inserted the full length of the retort, proceeded with difficulty through the smaller coal,

while it went at a more rapid rate through the larger coal.

The results of these tests prove conclusively that the Susie Coal from Kemmerer, Wyoming, can be processed without difficulty. The best technique for treatment would be to have one size of coal charged into the retort, and also to have a chain inserted in the charge as before explained.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 16

Date: April 10, 1934 Coal Kemmerer - Susie
Size of Coal: -1½" to +3/4" Superheated Steam Temp. 650°C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 44.0
2. Weight of residue from the retort, pounds... 31.25
3. Loss in weight, pounds 12.75, percent of total 29.0, pounds per ton of raw coal.... 580
4. Weight of raw coal, pounds per cu. ft..... 39.0
5. Weight of residue, pounds per cu. ft..... 20.75
6. Physical properties of the residue:
   (a) Color: black, dull luster,
   (b) Texture: dense with few expansion cracks,
   (c) Hardness: very good.

Gas

7. Total gas generated, cubic feet..... 59.5
   Cubic feet per ton of raw coal..... 2700

Crude Oil

8. Weight of crude oil, pounds..... 4.46
   Pounds per ton of raw coal..... 202

Superheated Steam

9. Apparent weight of steam used, pounds..... 84.0
   Pounds per ton of raw coal..... 3820

Saturated Steam

10. Weight of saturated steam used, pounds.....
    Pounds per ton of raw coal.....

PROXIMATE ANALYSIS OF COAL*

Moisture 1.2 Volatile Matter 37.0
Fixed Carbon 55.76 Ash 6.04
Sulphur 1.10 B.t.u. 13,590

*Source of Analysis: Dr. H. O. Cowles,
Utah Engineering Experiment Station.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 16

Date April 10, 1934 Barometer 25.4 in. of Hg.

Coal Kemmerer - Susie

Size of Coal -1½" to + 3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	44.0
Weight of residue from the retort, pounds	31.25
Weight of raw coal, pounds per cubic foot	39.00
Weight of residue, pounds per cubic foot	20.75
Final reading of gas meter No. 1, cubic feet	122.30
Initial reading of gas meter No. 1, cubic feet	62.8
Superheated steam:	
Final reading of condensate tank, pounds	85.0
Weight of water from Condensers No. 2 and 3	2.0
Initial reading of condensate tank, pounds	3.0
Saturated steam:	
Final reading of condensate tank, pounds	
Initial reading of condensate tank, pounds	
Weight of crude oil, pounds	4.46

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		20	20	20	20	20	20									
1:39																Sup. Stm. on.
1:45																Gas on.
1:52	659	418	263	140	103	98	98	96	32	24		20	7	0		
2:01	654	504	412	290	234	176	120	96	38	24		20	12	0		
2:10	650	497	436	320	287	208	142	92	32	24		15	5	0		
2:20	664	528	462	341	351	266	130	96	26	24		20	11	1		
2:40	652	513	471	368	410	376	253	93	36	24		15	10	1		
2:50	659	514	466	403	412	385	298	94	54	24		16	11	1		
3:12	650	523	478	476	424	394	320					23	14	1		
3:30	640	497	457	414	410	384	304					20	15	0		
3:45	650	504	460	419	414	391	321					19	13	0		
4:00	650	532	485	448	438	414	365					25	18	0		
4:04																Sup. Stm. off.
4:10															20	Sat. Stm. on.
4:20		T.C.	No.	7	Max.	of	402°.								20	Gas off.
4:40							200									Sat. Stm. off.
Ave.																

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 17

Date: April 11, 1934 Coal: Kemmerer - Susie
Size of Coal:** Superheated Steam Temp. 650°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	48.25**
2.	Weight of residue from the retort, pounds...	33.0
3.	Loss in weight, pounds 15.25, percent of total 31.7, pounds per ton of raw coal....	634
4.	Weight of raw coal, pounds per cu. ft.....	39.0
5.	Weight of residue, pounds per cu. ft.....	21.0
6.	Physical properties of the residue:	
	(a) Color: black, dull luster,	
	(b) Texture: dense with few expansion cracks,	
	(c) Hardness: very good.	

Gas

7.	Total gas generated, cubic feet.....	69.9
	Cubic feet per ton of raw coal.....	2900

Crude Oil

8.	Weight of crude oil, pounds.....	4.75
	Pounds per ton of raw coal.....	197

Superheated Steam

9.	Apparent weight of steam used, pounds.....	112.0
	Pounds per ton of raw coal.....	4650

Saturated Steam

10.	Weight of saturated steam used, pounds.....	70.5
	Pounds per ton of raw coal.....	2920

** -3/4" to +½" = 26.25 lbs.; -1½" to +3/4" = 22.0 lbs.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 17

Date April 11, 1934 Barometer 25.5 in. of Hg.

Coal Kemmerer - Susie

Size of Coal _____ Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	48.25 *
Weight of residue from retort, pounds	33.0
Weight of raw coal, pounds per cubic foot	39.0
Weight of residue, pounds per cubic foot	21.0
Final reading of gas meter No. 1, cubic feet	93.3
Initial reading of gas meter No. 1, cubic feet	23.1
Superheated steam:	
Final reading of condensate tank, pounds	105.0
Weight of water from Condensers No. 2 and 3	8.0
Initial reading of condensate tank, pounds	1.0
Saturated steam:	
Final reading of condensate tank, pounds	123.0
Initial reading of condensate tank, pounds	52.5
Weight of crude oil, pounds	4.72

(26.25 lbs. -3/4" to -1½)
* (22.0 " -1½" to + 3/4")

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		28	26	26	26	26	26									
10:34																Sup. Stm. on.
10:40																Gas on.
10:46	650	374	192	92	98	94	96					25	17½	1		
11:00	650	358	347	255	162	108	96	92	36	23		24	19	1		
11:45	664	354	334	327	230	138	110	92	28	22		19	13	1		
11:30	658	406	370	352	332	228	136	93	62	26		16	9	1		
11:45	638	474	416	406	426	388	268	93	48	25		20	13	1		
12:00	645	558	455	476	435	417	320	130	42	26		21	12	1		
12:15	654	532	488	443	450	428	362	142	44	25		17	9	1		
12:30	647	551	525	461	476	455	407	164	32	25		16	6	1		
12:35																Sup. Stm. off
12:45															15	Sat. stm. on.
12:50	445	213	220	312	327	372	368	240	90	24						Gas out
12:55																
1:00							172									Sat. stm. off.
Ave.																

TEST NO. 18

This test was made on a sample of subbituminous coal from the 84 foot seam of Adaville coal in Wyoming. This coal is generally known as Lazert coal.

The processing characteristics of this coal were observed to be identical with the subbituminous coals of Coalville.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 13

Date: April 23, 1934 Coal: Lazert - from Wyoming
Size of Coal: -2" to + 3/4" Superheated Steam Temp. 650°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	45.0
2.	Weight of residue from the retort, pounds...	25.5
3.	Loss in weight, pounds 19.5, percent of total 43.4, pounds per ton of raw coal....	867
4.	Weight of raw coal, pounds per cu. ft.....	39.0
5.	Weight of residue, pounds per cu. ft.....	38.0
6.	Physical properties of the residue:	
	(a) Color: black, bright luster,	
	(b) Texture: finely cracked,	
	(c) Hardness: soft, very friable.	

Gas

7.	Total gas generated, cubic feet.....	76.0
	Cubic feet per ton of raw coal.....	3380

Crude Oil

8.	Weight of wet crude oil, pounds.....	3.1
	Pounds per ton of raw coal.....	138

Superheated Steam

9.	Apparent weight of steam used, pounds.....	78.5
	Pounds per ton of raw coal.....	3490

Saturated Steam

10.	Weight of saturated steam used, pounds.....	58.5
	Pounds per ton of raw coal.....	2600

PROXIMATE ANALYSIS OF COAL*

Moisture 8.54 Volatile Matter 40.8
Fixed Carbon ~~53.27~~ 46.13 Ash 3.93
Sulphur 0.45 B.t.u. 11,709

*Source of Analysis: Dr. H. O. Cowles,
Utah Engineering Experiment Station.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 18

Date April 23, 1934 Barometer 25.35 in. of Hg.
Coal Lazert
Size of Coal - 2" to ¼ 3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	45.0
Weight of residue from the retort, pounds	25.50
Weight of raw coal, pounds per cubic foot	39.0
Weight of residue, pounds per cubic foot	38.0
Final reading of gas meter No. 1, cubic feet	206.0
Initial reading of gas meter No. 1, cubic feet	130.0
Superheated steam:	
Final reading of condensate tank, pounds	78.5
Weight of water from Condensers No. 2 and 3	8.0
Initial reading of condensate tank, pounds	8.0
Saturated steam:	
Final reading of condensate tank, pounds	108.0
Initial reading of condensate tank, pounds	49.5
Weight of crude oil, pounds $4.5 \times 0.685 \times \frac{2000}{45} = 137$#/ton	3.1

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
12:00	650	120	96	74	98	98	102	102	26	26		15	0			Sup. Stm.
12:10												16	6			on
12:15	647	438	284	140	108	98	98	98	38	34		16	6			Gas on.
12:30	656	532	464	352	305	168	115	98	40	30		16	6			
12:45	666	548	536	448	438	355	258	97	38	30		16	6			
1:00	660	556	528	490	501	458	408									
1:05																Sup. Stm.
1:10														0	15	off.
1:15		340	379	344	438	458	443	215	44	28				0	15	Sat. Stm.
1:20																on.
																Gas Out.
Ave.																

TEST NO. 19

This test was made on a fresh sample of Sevier Valley coal as previously explained in Test No. 9.

The smokeless fuel was of much better quality than that produced from the previous coal sample. The writer believes that this coal from the Sevier Valley Coal Mining Company in Saline Canyon, Utah, would make a suitable domestic smokeless fuel. The raw coal also gives yields of gas and oil as high as most Carbon County coals.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF PRELIMINARY TEST NO. 19

Date: April 26, 1934 Coal: Sevier Valley
Size of Coal: -1-5/8" to + 3/4" Superheated Steam Temp. 650°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	50.0
2.	Weight of residue from the retort, pounds...	32.5
3.	Loss in weight, pounds 17.5, percent of total 35, pounds per ton of raw coal.....	700
4.	Weight of raw coal, pounds per cu. ft.....	
5.	Weight of residue, pounds per cu. ft.....	30.0
6.	Physical properties of the residue:	
	(a) Color: black, dull luster,	
	(b) Texture: fine with surface cracks,	
	(c) Hardness: good.	

Gas

7.	Total gas generated, cubic feet.....	77.7
	Cubic feet per ton of raw coal.....	3110

Crude Oil

8.	Weight of wet crude oil, pounds.....	6.73
	Pounds per ton of raw coal.....	269

Superheated Steam

9.	Apparent weight of steam used, pounds.....	70
	Pounds per ton of raw coal.....	2800

Saturated Steam

10.	Weight of saturated steam used, pounds.....	52.5
	Pounds per ton of raw coal.....	2100

PROXIMATE ANALYSIS OF COAL*

Moisture 2.48 Volatile Matter 40.9
Fixed Carbon ~~51.10~~ 48.62 Ash 8.0
Sulphur 0.46 B.t.u. 13,000

*Source of Analysis: Dr. H. O. Cowles,
Utah Engineering Experiment Station.

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

LABORATORY DATA SHEET FOR PRELIMINARY TEST NO. 19

Date April 26, 1934 Barometer 25.50 in. of Hg.

Coal Sevier Valley

Size of coal -1 5/8" to + 3/4" Superheated Steam Temp. 650 °C.

Weight of raw coal charged, pounds	50.0
Weight of residue from the retort, pounds	32.5
Weight of raw coal, pounds per cubic foot	
Weight of residue, pounds per cubic foot	30.0
Final reading of gas meter No. 1, cubic feet	110.2
Initial reading of gas meter No. 1, cubic feet	32.5
Superheated steam:	
Final reading of condensate tank, pounds	74.0
Weight of water from Condensers No. 2 and 3	40.0
Initial reading of condensate tank, pounds	4.0
Saturated steam:	
Final reading of condensate tank, pounds	90.0
Initial reading of condensate tank, pounds	37.5
Weight of crude oil, pounds	6.73

Time	Thermocouple Readings - °C.										Ave.	Stm. Pressures				Remarks
	1	2	3	4	5	6	7	8	9	10		1	2	3	4	
		23	23	23	23	24	23									
11:30	638											8	0	1		Sup. Stm.
11:40	650	305	140	83	96	96	96					8	3	1		on.
12:00	645	512	391	241	206	147	108					20	9	1		Gas on.
12:15	631	539	494	417	408	318	248					21	10	1		
12:30	654	551	513	457	464	419	362					21	10	1		
12:35							380									Sup. Stm. off.
12:44																Sat. Stm. on.
12:58																Gas stpd.
1:00		140	160	192	192	243	256									
1:10							185									Sat. Stm. off.
Ave.																

CONCLUSIONS TO PRELIMINARY TESTS

Throughout these tests, the writer observed many salient facts which may be summed up briefly as follows:

1. All of the bituminous coals tend to soften while processing in varying degrees but none of them have the extreme fusing properties which are required for successful high-temperature coke manufacture. Sunnyside coal is the most important coking coal in Utah, but was not used in this investigation.

2. The greater portion of our Western bituminous coals can be easily discharged from a slightly tapered retort. By the aid of a chain placed longitudinally in the center of the retort, a convenient support is provided throughout the coal charge to maintain an "open" charge. With a tapered retort, the ease with which the smokeless fuel could be discharged would be increased, but this was not found necessary.

3. Upon carbonization, the smokeless fuel produced from each coal did not adhere to the walls of the retort, and left the inside surface as smooth as it was before carbonization took place.

4. Practically all Rocky Mountain coals, exhibiting minor fusing characteristics, are, therefore, especially well adapted to low-temperature carbonization in r retorts. All subbituminous coals are likewise well adapted to this method of treatment.

5. With the present installation, the softening and compacting of the coal could be detected by noting the steam pressure drop between the outlet and the inlet of the superheater coil. Thus, when this pressure drop was 3 to 4 pounds per square inch, the flow of superheated steam through the coil and into the retort was reduced to a value which permitted no heat transfer to the coal to take place. As pointed out above this pressure drop is caused by compressing of the coal lumps during heating which reduces the area for the flow of the steam, and consequently, the pressure at the outlet of the superheater is increased so that a smaller amount of steam flows through the coil.

6. All of the crude oils derived from the coals possessed the same general physical characteristics as to color, viscosity, and density.

7. From 85 to 90 per cent of the smokeless fuel produced from the bituminous coals was above 3/4 inch, which

was the minimum size of the coal as originally charged. Consequently very little "breeze" or fine carbonized coal was produced.

8. The subbituminous coals were observed to disintegrate upon processing, but the writer found that this degradation could be materially reduced by employing a slower rate of heat transfer. By using this method, the time required for distillation would be such that at least 5 complete distillations could be easily made per 24 hours per retort.

9. From inspection of Table XII, it can be seen that bituminous coals give from 1230 to 1400 pounds of smokeless fuel, from 2100 to 3200 cubic feet of artificial gas at test conditons, having a heating value ranging from 800 to 1050 B.T.U. at 60° F., and 30" of mercury pressure, and also, from 269 to 319 pounds (32 to 38 gallons) of dry crude oil per ton of coal.

The subbituminous coals yield lower quantities of smokeless fuel and oil and give larger quantities of artificial gas. The yields of these items on a per ton basis were found to be as follows:

Smokeless fuel: 1100 to 1200 pounds;

Gas: 3100 to 3400 cubic feet having a heating value

ranging from 578 to 800 B.T.U. per cubic foot;

Crude oil: 138 to 200 pounds (16 to 24 gallons).

TABLE XII
TABULATED RESULTS OF PRELIMINARY TESTS

Test No.	Coal	Pounds of Smokeless Fuel per Ton of Coal	Cu. Ft. Gas per Ton of Coal at Test Conditions	Pounds of Crude Oil per Ton of Coal	Gas Analysis - Per Cent by Volume - 60°F., 30" Hg.						
					CO_2	Ill.	CO	H_2	CH_4	C_2H_6	B.t.u. per cu.ft.
1	Castle Gate No. 2 Mine - "D" Seam	1400	2630	239							
2	Castle Gate No. 3 Mine - "F" Seam	1361	2540	253							
3	Clearcreek	1326	2660	249							
4	King	1277	2185	286							
5	King	1308	2475	285	14.9	9.2	9.7	16.7	40.0	7.7	901
6	Aberdeen	1358	3260	283							
7	Aberdeen	---	2885	259							
8	Standard	1370	2690	275	15.8	14.6	11.3	5.7	52.8	---	1018
9	Sevier Valley	1231	2760	275	18.3	8.4	10.7	16.8	36.0	9.6	876
10	Rilda Canyon	1277	2135	319							
11	Grass Creek	1106	3100	201	26.0	7.6	15.5	9.4	32.7	9.4	805
12	Weber	1130	3350	201							
13	Weber	1200	3135	186							
14	Rock Springs	1288	2540	221							
15	Kemmerer No. 5	1514	1650	210							
16	Kemmerer - Susie	1420	2700	202	13.2	9.5	8.4	19.8	41.5	8.7	951
17	Kemmerer - Susie	1366	2900	197							
18	Lazert	1133	3380	138	33.8	4.2	15.5	13.1	29.6	3.5	578
19	Sevier Valley	1300	3110	269	19.0	7.75	10.9	21.6	35.3	5.43	789

METHOD OF MAKING DETAILED TESTS

General. The purpose of these tests was to provide accurate experimental data concerning the heat required, the steam consumption, the time necessary to distill the coal, the mechanism of the heat transfer and the rate of evolution of the generated gas.

Three separate tests were conducted: (1) At 538° C. (1000° F.), (2) at 650° C (1202° F.), and (3) at 740°C. (1364° F.). The size of the coal lumps were within the range of 2" to 3/4". Therefore, the results of the three tests can be compared on the same basis as well as can the results of the preliminary tests.

Except for the following items the instructions for making the Preliminary Tests were followed:

All of the instruments aforementioned were read every five minutes.

A few minutes before the superheated steam was admitted to the retort, thermocouples numbers 2 to 6 inclusive were read for the purpose of determining the average initial temperature of the coal in the retort.

When the temperature of the superheated steam reached the desired value, the superheated steam was passed into the retort.

After five minutes elapsed the following readings were made, in the following order:

(a) Thermocouple readings from one to ten inclusive.

(b) Reading of the gas meter measuring the generated gas. The initial reading of this meter was observed when the gas began to burn steadily, and the time noted. The gas pressure was also noted.

(c) The pressure gauges were read.

From these data, curves were plotted on standard cross-section paper with time in minutes as abscissae and retort temperatures in degrees Cent., cubic feet of generated gas, the gas pressure, and back pressure on the retort, as ordinates.

From this point on, the above readings were made every five minutes. The rate of rise of the gasometer float was adjusted so that approximately 0.1 of a cubic foot of gas was witheld every ten minutes.

When number seven thermocouple reached 400° C., or when the rate of gas generation began to decline and the color of the flame changed from orange to light yellow, the flow of superheated steam was diverted from the retort to the atmosphere.

The flow of condensed steam from the decanter was then stopped, and the weight of water in the condensate tank was determined.

When the condensate tank had been drained, the readings specified above were made and the time noted. Immediately thereafter, the saturated steam was admitted to the retort at 10 to 20 pounds pressure and the time noted when the steam was first admitted. For every 5 minutes thereafter the readings specified above were made and recorded.

Dry-quenching proceeded until number seven thermocouple read 200° C. The instant the flow of generated gas ceased was noted.

The level of the oil in the decanter was brought to its level at the beginning of the dry-quenching period and then the decanter was removed. The weight of water in the condensate tank was then read.

The smokeless fuel was removed and allowed to fall into a container. The coal was immediately spread out in one continuous line on a clean floor. A representative sample of the fuel was obtained for analytical purposes. After cooling, the residue was weighed. Also a screen analysis was made.

The entire condensing system was thoroughly cleaned from oil with superheated steam.

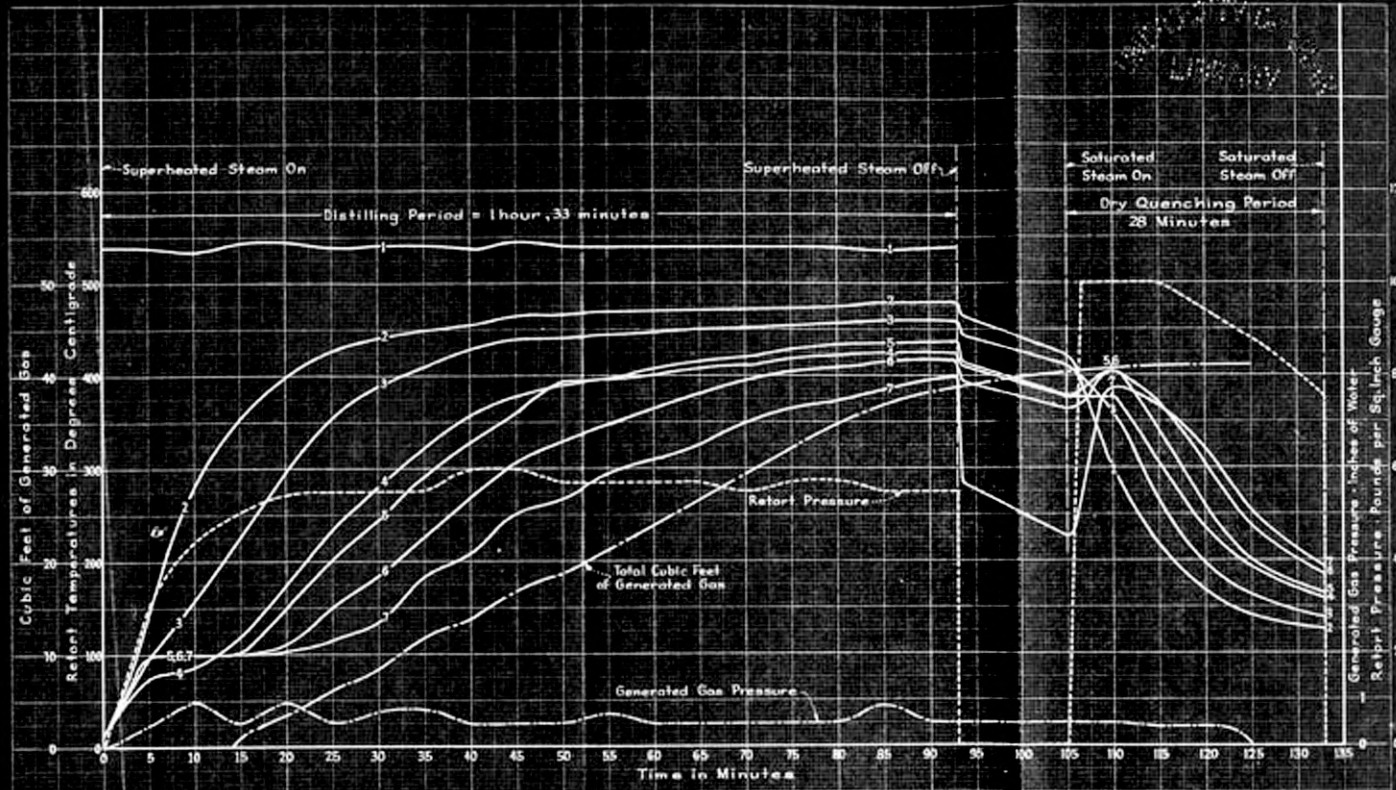
The gas oil used for absorbing the light oil from the scrubber was weighed in grams. The percentage of light oil

was calculated after a fractional distillation was made on the used gas oil.

DETAILED TESTS

The detailed tests were conducted as previously outlined on Aberdeen, Grass Creek, and Rock Springs coals. These coals were chosen as being representative coals of the Rocky Mountain Coal Province.

Curves depicting the salient operations of the carbonizing plant are first presented, after which all of the detailed data are given.



LOG OF PLANT OPERATION
for
DETAILED TEST No. 1
ON ABERDEEN RSA COAL

FIG. 7

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 1

Date: February 13, 1934 Barometer: 25.61 in. of Hg.

Coal: Aberdeen

Size of Coal: -1-5/8" to + 3/4" Superheated Steam Temp. 538°C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 44.75
2. Weight of residue from the retort, pounds... 32.4
3. Loss in weight, pounds 12.35, percent of total 27.6, pounds per ton of raw coal.... 552.00
4. Weight of raw coal, pounds per cu. ft..... 41.25
5. Weight of residue, pounds per cu. ft. (above 3/4").... 24.25

Gas, 60°F.. 30" Hg.

6. Total gas generated, cubic feet..... 34.8
   Cubic feet per ton of raw coal.....1555.0

Crude Oil

7a. Weight of crude oil, pounds..... 5.7
   Pounds per ton of raw coal..... 255.0
7b. Weight of light oil, pounds..... 0.097
   Pounds per ton of raw coal..... 4.34

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B.t.u.
Raw Coal	3.2	39.7	50.8	6.3	0.53	13,300
Smokeless Fuel	---	17.0	75.9	7.1	0.55	12,900

Gas Analysis, Percent by Volume, Air Free

Carbon dioxide, CO_2..... 16.6
Illuminants..... 12.4
Oxygen, O_2..... ---
Hydrogen, H_2..... 10.1
Carbon Monoxide, CO..... 8.1
Methane, $C H_4$..... 39.5
Ethane, $C_2 H_6$..... 13.3
Nitrogen, N_2..... ---
Heating value, B.t.u. per cu.ft. 60°F., 30" Hg..1064
Weight of gas, pounds per 1000 cu. ft..... 73

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds		552
9.	Weight of total oil, pounds	259.3	
10.	Weight of gas, pounds	113.5	
11.	Weight of free moisture, pounds	64.	
12.	Weight of water formed, pounds	115.2	
	Total		552.0

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds		2.73
14.	Weight of free moisture in the raw coal, pounds	.032	
15.	Weight of water formed from the coal charged.	.058	
	Total	.090	
16.	Weight of water in the wet crude oil, pounds.	.018	
	Difference	.072	
17.	Actual weight of steam used, pounds		2.66
18.	Degrees of rise of retort temperature - °C		436.5
19.	Actual weight of steam used, pounds per pound of coal per deg. C		.0061

Saturated Steam per Pound of Coal

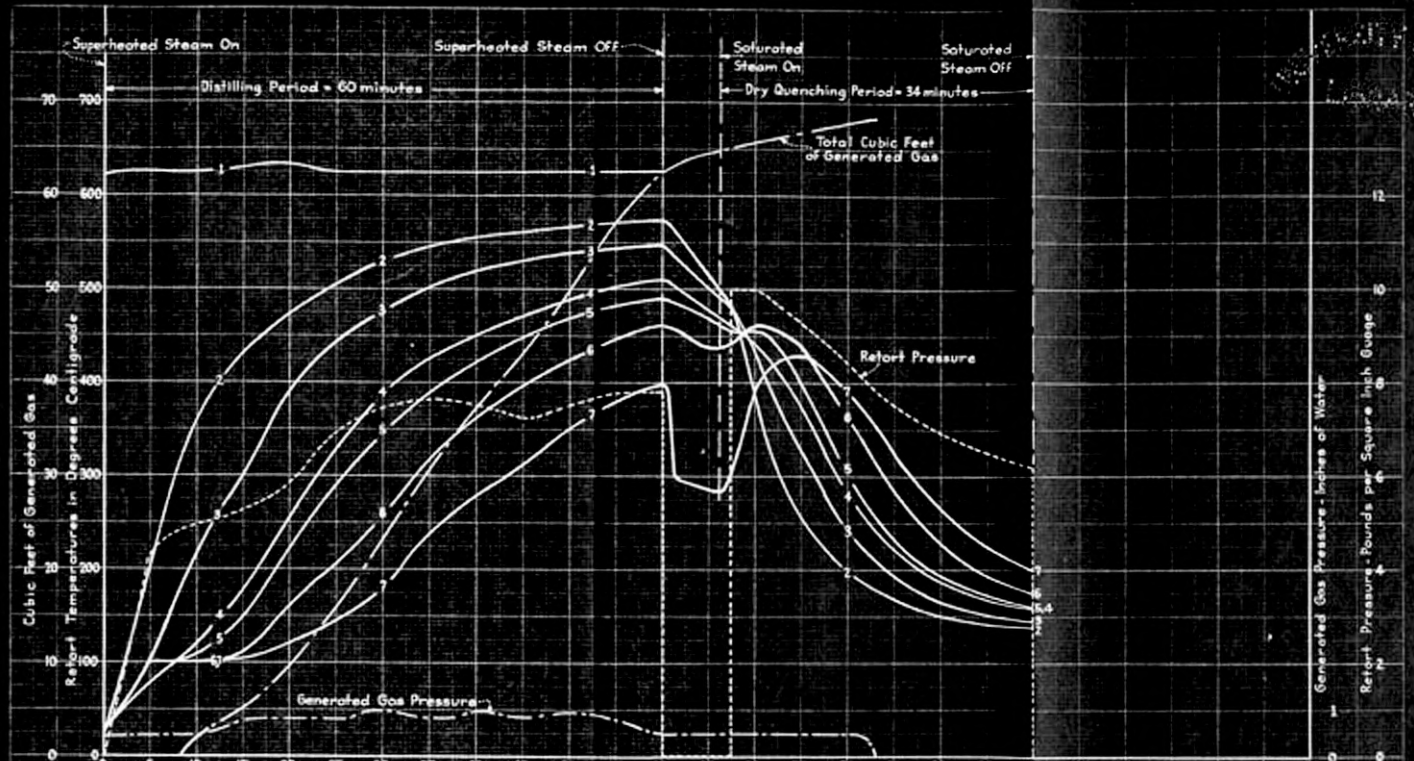
20.	Weight of saturated steam used, pounds	1.262
21.	Degrees of lowering of retort temperature °C	253.4
22.	Weight of saturated steam per pound of coal per deg. C	.0049

Heat Balance for One Retort, per Ton of Coal

		Thous and B. t. u.	Per Cent of Total
23.	Total heat content of superheated steam entering retort	8260	100.00
24.	Heat given to the retort	263	3.18
25.	Heat given to the residue	209	2.53
26.	Heat in volatiles plus fixed gases	46	0.57
27.	Heat content of steam leaving retort	6970	84.38
28.	Heat lost by radiation	17	0.21
29.	Heat unaccounted for	755	9.13

Miscellaneous Data

30.	Time required for destructive distillation, hours	1.550
31.	Time required for dry quenching, hours	0.466



LOG OF PLANT OPERATION
for
DETAILED TEST No. 2
ON ABERDEEN PEA COAL

FIG. 8

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 2

Date: February 16. 1934 Barometer: 25.38 in. of Hg.
Coal: Aberdeen
Size of Coal: -1-5/8" to +3/4" Superheated Steam Temp. 650°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	45.50
2.	Weight of residue from the retort, pounds...	30.86
3.	Loss in weight, pounds 14.64, percent of total 32.2, pounds per ton of raw coal....	644
4.	Weight of raw coal, pounds per cu. ft.....	42.75
5.	Weight of residue, pounds per cu. ft.....	22.75

Gas. 60°F., 30" Hg.

6.	Total gas generated, cubic feet.....	56.9
	Cubic feet per ton of raw coal.....	2500

Crude Oil

7a.	Weight of crude oil, pounds.....	6.12
	Pounds per ton of raw coal.....	269
7b.	Weight of light oil, pounds.....	0.114
	Pounds per ton of raw coal.....	5.0

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B. t. u.
Raw Coal	3.2	39.7	50.8	6.3	0.53	13,300
Smokeless Fuel	---	17.5	74.1	8.4	0.45	13,000

Gas Analysis. Per Cent by Volume. Air Free

Carbon dioxide, CO_2.....	15.2
Illuminants.....	9.1
Oxygen, O_2	---
Hydrogen, H_2	15.8
Carbon Monoxide, CO.....	10.3
Methane, CH_4	25.8
Ethane, C_2H_6	23.8
Nitrogen, N_2	---
Heating value, B.t.u. per cu. ft. 60°F., 30" Hg.	1045
Weight of gas, pounds per 1000 cu. ft.....	70.67

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds.....		644
9.	Weight of total oil, pounds.....	274	
10.	Weight of gas, pounds.....	176	
11.	Weight of free moisture, pounds.....	64	
12.	Weight of water formed, pounds.....	130	
		Total...	644

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds.....		1.81
14.	Weight of free moisture in the raw coal, pounds.....	.032	
15.	Weight of water formed from the coal charged.....	.065	
	Total.....	.097	
16.	Weight of water in the wet crude oil, pounds.....	.019	
	Difference	.078	
17.	Actual weight of steam used, pounds.....		1.73
18.	Degrees of rise of retort temperature °C.....		493
19.	Actual weight of steam used, pounds per pound of coal per deg. C.....		.0035

Saturated Steam per Pound of Coal

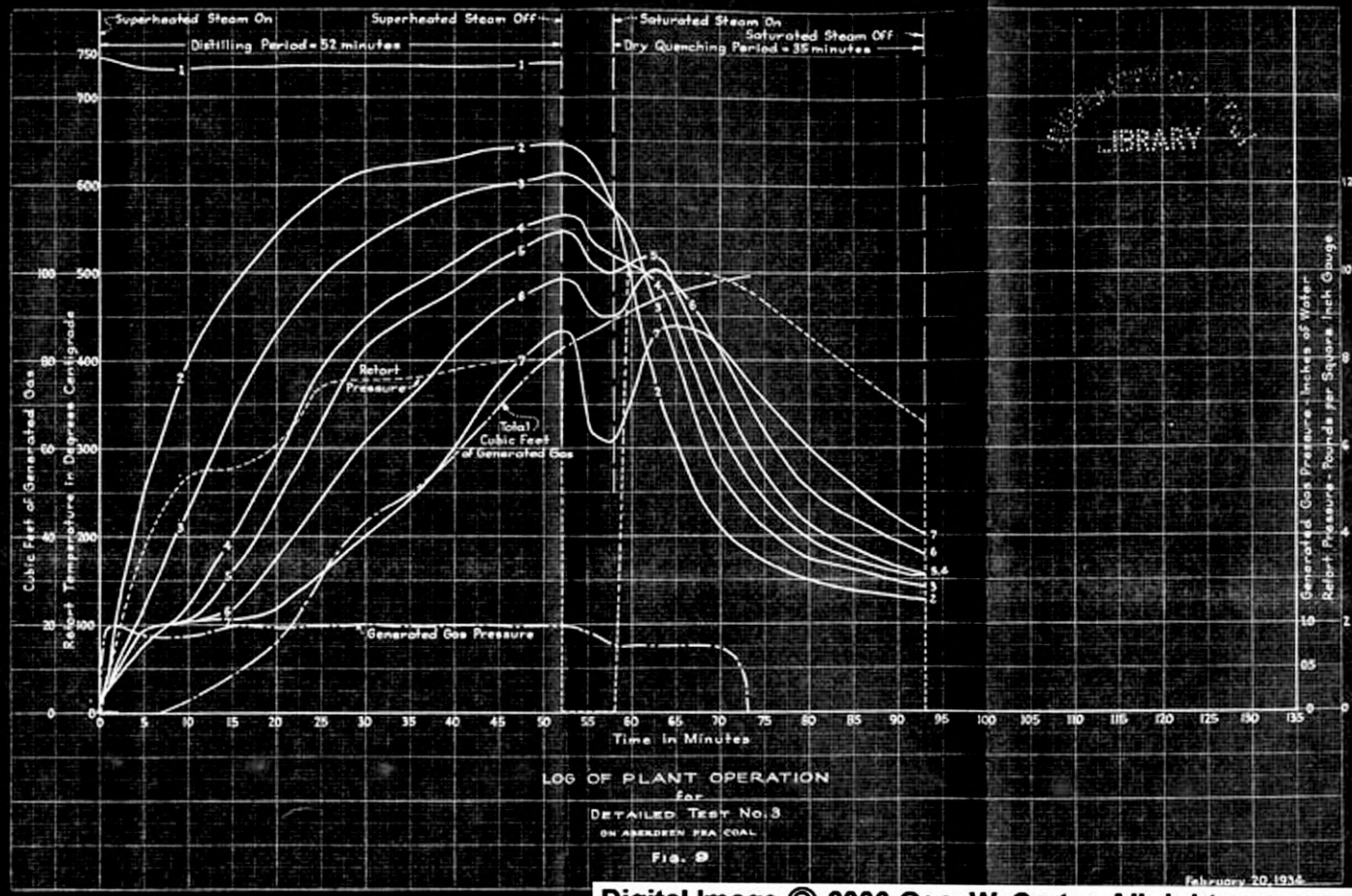
20.	Weight of saturated steam used, pounds.....	1.57
21.	Degrees of lowering of retort temperature °C.....	351.5
22.	Weight of saturated steam per pound of coal per deg. C.....	.00447

Heat Balance for One Retort, per Ton of Coal

		Thous and B. t. u.	Per Cent of Total
23.	Total heat content of superheated steam entering retort.....	5730	100.0
24.	Heat given to the retort.....	293	5.12
25.	Heat given to the residue.....	241	4.22
26.	Heat in volatiles plus fixed gases	46	0.82
27.	Heat content of steam leaving retort	4550	79.40
28.	Heat lost by radiation.....	17	0.30
29.	Heat unaccounted for.....	583	10.14

Miscellaneous Data

30.	Time required for destructive distillation, hours.....	1.0
31.	Time required for dry quenching, hours....	.57



LOG OF PLANT OPERATION

for

DETAILED TEST No. 3

ON ABERDEEN SEA COAL

FIG. 9

February 20, 1936

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 3

Date: February 20, 1934 Barometer: 25.04 in. of Hg.
Coal: Aberdeen
Size of Coal: -1-5/8" to +3/4" Superheated Steam Temp. 740°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	44.0
2.	Weight of residue from the retort, pounds...	29.0
3.	Loss in weight, pounds 15.0, percent of total 34.1, pounds per ton of raw coal....	682.0
4.	Weight of raw coal, pounds per cu. ft.....	41.0
5.	Weight of residue, pounds per cu. ft.....	21.75

Gas, 60°F., 30" Hg.

6.	Total gas generated, cubic feet.....	82.4
	Cubic feet per ton of raw coal.....	3750

Crude Oil

7a.	Weight of crude oil, pounds.....	5.06
	Pounds per ton of raw coal.....	230
7b.	Weight of light oil, pounds per ton of raw coal.....	5.0

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B. t. u.
Raw Coal	3.2	39.7	50.8	6.3	0.53	13,300
Smokeless Fuel	---	14.0	77.0	9.0	0.40	13,000

Gas Analysis, Per Cent by Volume, Air Free

Carbon dioxide, $C O_2$.....	15.7
Illuminants.....	7.1
Oxygen, O_2.....	---
Hydrogen, H_2.....	10.2
Carbon Monoxide, C O.....	12.7
Methane, $C H_4$.....	36.1
Ethane, $C_2 H_6$.....	18.2
Nitrogen, N_2.....	---
Heating value, B.t.u. per cu. ft. 60° F., 30"Hg..	970
Weight of gas, pounds per 1000 cu. ft.....	69.5

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds.....		682
9.	Weight of total oil, pounds.....	235	
10.	Weight of gas, pounds.....	261	
11.	Weight of free moisture, pounds.....	64	
12.	Weight of water formed, pounds.....	122	
	Total...		682

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds.....		1.62
14.	Weight of free moisture in the raw coal, pounds.....	.032	
15.	Weight of water formed from the coal charged	.061	
	Total...	.093	
16.	Weight of water in the wet crude oil, pounds.....	.022	
	Difference	.071	
17.	Actual weight of steam used, pounds.....		1.55
18.	Degrees of rise of retort temperature °C.....		556
19.	Actual weight of steam used, pounds per pound of coal per deg. C.....		.0028

Saturated Steam per Pound of Coal

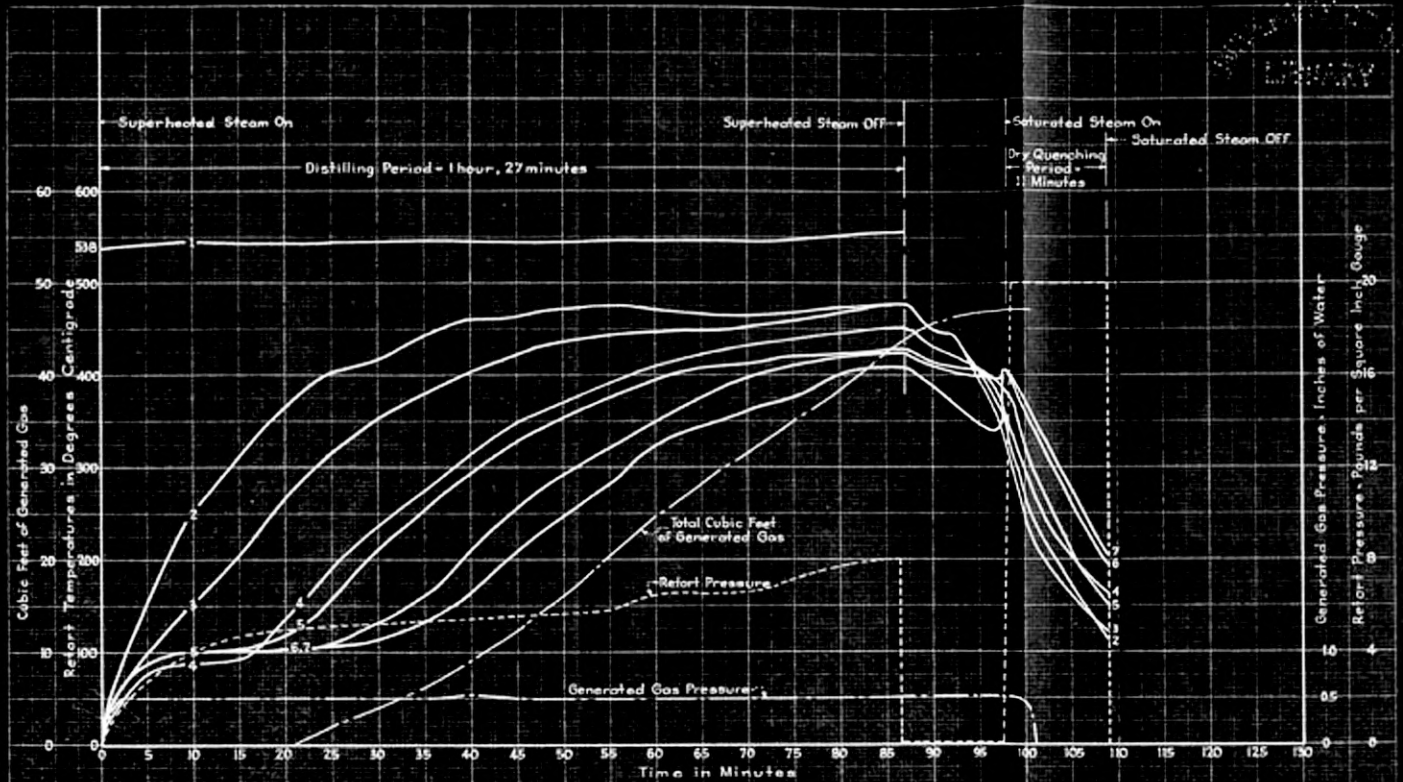
20.	Weight of saturated steam used, pounds.....	1.55
21.	Degrees of lowering of retort temperature °C.....	410
22.	Weight of saturated steam per pound of coal per deg. C.....	.0038

Heat Balance for One Retort, per Ton of Coal

		Thous and B. t. u.	Per Cent of Total
23.	Total heat content of superheated steam entering retort....	5380	100.00
24.	Heat given to the retort.....	344	6.40
25.	Heat given to the residue.....	266	4.94
26.	Heat in volatiles plus fixed gases	48	.89
27.	Heat content of steam leaving retort.....	4040	75.08
28.	Heat lost by radiation.....	17	.32
29.	Heat unaccounted for.....	665	12.37

Miscellaneous Data

30.	Time required for destructive distillation, hours.....	.866
31.	Time required for dry quenching, hours.....	.583



LOG OF PLANT OPERATION

for

DETAILED TEST No. 4

GRASS CREEK COAL FROM COALVILLE, UTAH

FIG. 10

April 21, 1934

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 4

Date: April 21, 1934 Barometer 25.46 in. of Hg.
Coal: Grass Creek from Coalville, Utah
Size of Coal: -2" + 3/4" Superheated Steam Temp. 538°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	45.0
2.	Weight of residue from the retort, pounds...	27.25
3.	Loss in weight, pounds 17.75, percent of total 39.4, pounds per ton of raw coal....	789
4.	Weight of raw coal, pounds per cu. ft.....	40.75
5.	Weight of residue, pounds per cu. ft.....	39.6

Gas 60°F., 30" Hg.

6.	Total gas generated, cubic feet.....	39.1
	Cubic feet per ton of raw coal.....	1735

Crude Oil

7a.	Weight of crude oil, pounds.....	4.06
	Pounds per ton of raw coal.....	180
7b.	Weight of light oil, pounds per ton of raw coal.....	5

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B. t. u.
Raw Coal	12.53	35.8	47.83	3.84	1.5	10,900
Smokeless Fuel	---	37.0	57.3	5.7	1.1	13,750

Gas Analyses, Percent by Volume, Air Free

Carbon dioxide, CO_2.....	30.90
Illuminants.....	6.52
Oxygen, O_2.....	---
Hydrogen, H_2.....	7.13
Carbon Monoxide, CO.....	12.10
Methane, CH_4.....	32.30
Ethane, C_2H_6.....	5.96
Nitrogen, N_2.....	5.09
Heating value, B.t.u. per cu. ft. 60°F., 30" Hg..	689
Weight of gas, pounds per 1000 cu. ft.....	78

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds.....		789
9.	Weight of total oil, pounds.....	185	
10.	Weight of gas, pounds.....	135	
11.	Weight of free moisture, pounds.....	251	
12.	Weight of water formed, pounds.....	218	
	Total....		789

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds.....		3.03
14.	Weight of free moisture in the raw coal, pounds.....	0.125	
15.	Weight of water formed from the coal charged.	0.109	
	Total.....	0.234	
16.	Weight of water in the wet crude oil, pounds.	0.004	
	Difference....	0.230	
17.	Actual weight of steam used, pounds.....		2.80
18.	Degrees of rise of retort temperature °C.....		421
19.	Actual weight of steam used, pounds per pound of coal per deg. C.....		0.0066

Saturated Steam per Pound of Coal

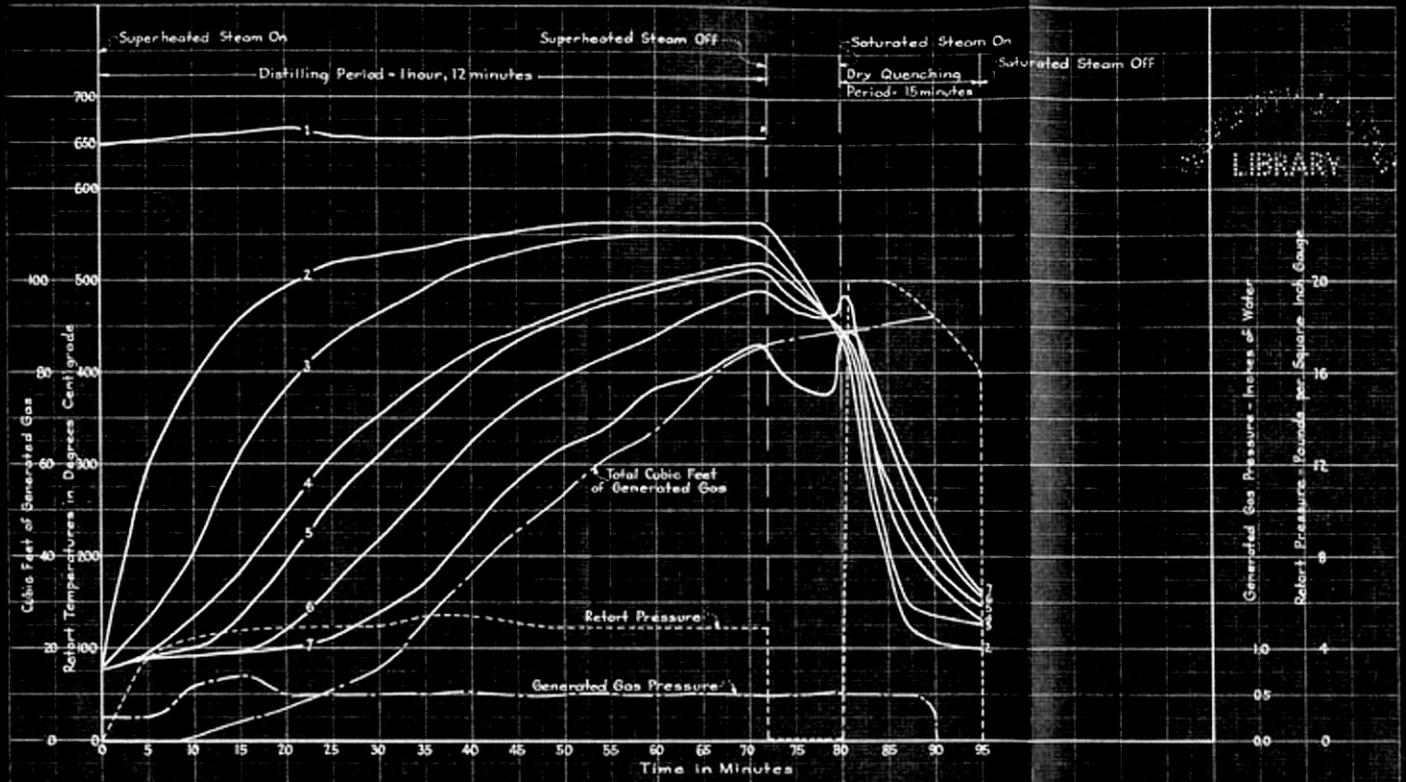
20.	Weight of saturated steam used, pounds.....	1.14
21.	Degrees of lowering of retort temperature °C.....	292
22.	Weight of saturated steam per pound of coal per deg. C.....	.0039

Heat Balance for One Retort, per Ton of Coal

		Thousand B. t. u.	Per Cent of Total
23.	Total heat content of superheated steam entering retort.....	8700	100.00
24.	Heat given to the retort.....	252	2.89
25.	Heat given to the residue.....	184	2.12
26.	Heat in volatiles plus fixed gases....	35	.40
27.	Heat content of steam leaving retort..	7510	86.35
28.	Heat lost by radiation.....	17	0.19
29.	Heat unaccounted for.....	702	8.05

Miscellaneous Data

30.	Time required for destructive distillation, hours.....	1.45
31.	Time required for dry quenching, hours.....	0.18



LOG OF PLANT OPERATION
For
DETAILED TEST No. 5
GRASS CREEK COAL FROM COALVILLE, UTAH

FIG. 11

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 5

Date: April 21, 1934 Barometer: 25.42 in. of Hg.
Coal: Grass Creek from Coalville, Utah
Size of Coal: -2" + 3/4" Superheated Steam Temp. 650°C.

Coal and Residue

1. Weight of raw coal charged, pounds..... 45
2. Weight of residue from the retort, pounds.... 24.25
3. Loss in weight, pounds 20.75, percent of total 46, pounds per ton of raw coal..... 922
4. Weight of raw coal, pounds per cu. ft..... 40.75
5. Weight of residue, pounds per cu. ft..... ---

Gas 60°F.. 30" Hg.

6. Total gas generated, cubic feet..... 77.1
Cubic feet per ton of raw coal.....3430

Crude Oil

7a. Weight of crude oil, pounds..... 4.75
Pounds per ton of raw coal..... 211
7b. Weight of light oil, pounds per ton of raw coal..... 5

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B.t.u.
Raw Coal	12.53	35.8	47.83	3.84	1.5	10,900
Smokeless Fuel	---	30.5	62.0	7.5	1.0	13,248

Gas Analysis, Percent by Volume, Air Free

Carbon dioxide, $C O_2$..... 24.5
Illuminants..... 6.6
Oxygen, O_2..... ---
Hydrogen, H_2..... 20.9
Carbon Monoxide C O..... 12.1
Methane, $C H_4$..... 33.0
Ethane, $C_2 H_6$..... 2.9
Nitrogen, N_2..... ---
Heating Value, B.t.u. per cu. ft., 60°F., 30" Hg. 695
Weight of gas, pounds per 1000 cu. ft..... 65.5

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds		922
9.	Weight of total oil, pounds	216	
10.	Weight of gas, pounds	225	
11.	Weight of free moisture, pounds	251	
12.	Weight of water formed, pounds	230	
	Total		922

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds		1.64
14.	Weight of free moisture in the raw coal, pounds	0.125	
15.	Weight of water formed from the coal charged	0.115	
	Total	0.240	
16.	Weight of water in the wet crude oil, pounds	0.022	
	Difference	0.218	
17.	Actual weight of steam used, pounds		1.42
18.	Degrees of rise of retort temperature °C		457
19.	Actual weight of steam used, pounds per pound of coal per deg. C		.0032

Saturated Steam per Pound of Coal

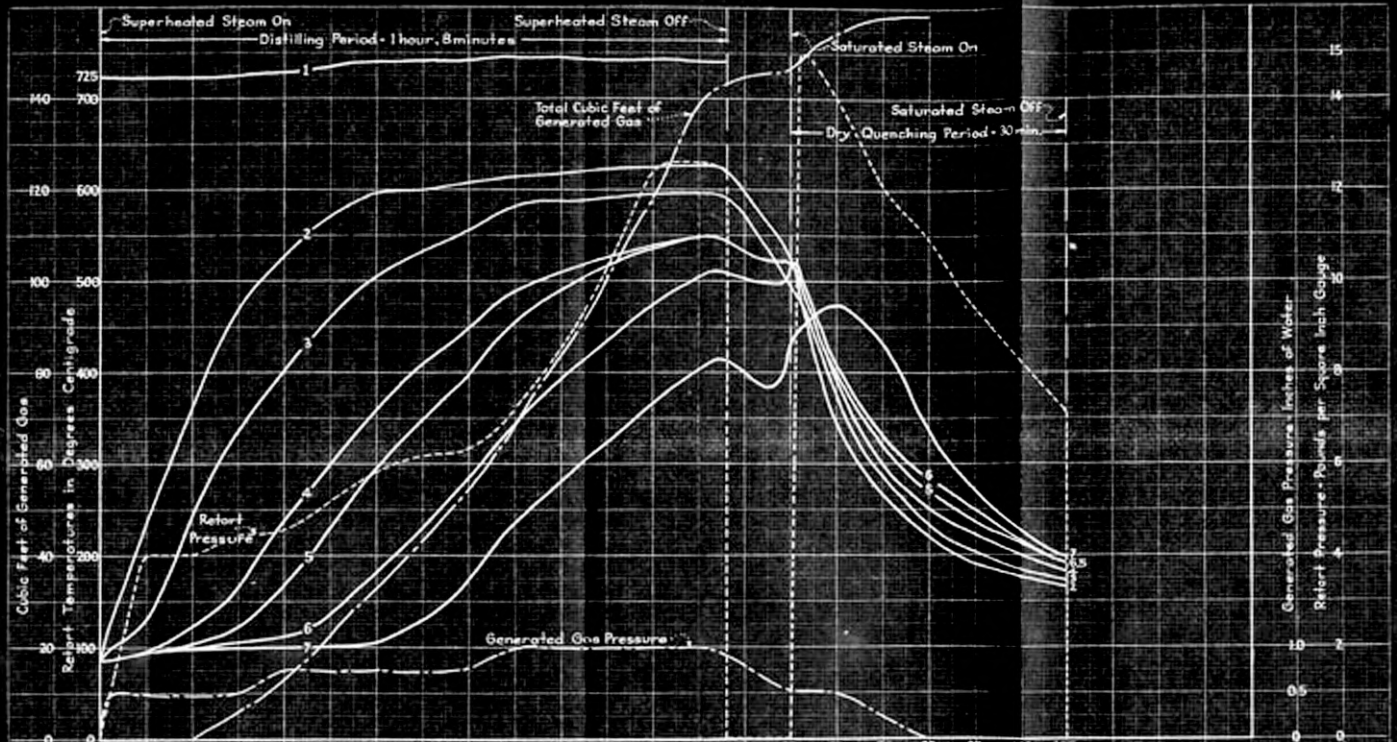
20.	Weight of saturated steam used, pounds	1.51
21.	Degrees of lowering of retort temperature °C	384.5
22.	Weight of saturated steam per pound of coal per deg. C	.0039

Heat Balance for One Retort, per Ton of Coal

		Thousand B. t. u.	Per cent of Total
23.	Total heat content of superheated steam entering retort	4710	100.00
24.	Heat given to the retort	270	5.73
25.	Heat given to the residue	177	3.76
26.	Heat in volatiles plus fixed gases	34	0.72
27.	Heat content of steam leaving retort	4140	87.90
28.	Heat lost by radiation	17	0.36
29.	Heat unaccounted for	72	1.53

Miscellaneous Data

30.	Time required for destructive distillation, hours	1.2
31.	Time required for dry quenching, hours	0.25



LOG OF PLANT OPERATION
For
DETAILED TEST No. 6
GRASS CREEK COAL FROM COALVILLE, UTAH

FIG. 12

April 23, 1934

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 6

Date: April 23, 1934 Barometer: 25.40 in. of Hg.
Coal: Grass Creek from Coalville
Size of Coal: -2" to +3/4 Superheated Steam Temp. 725°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	45.0
2.	Weight of residue from the retort, pounds...	24.75
3.	Loss in weight, pounds 20.25, percent of total 45, pounds per ton of raw coal.....	901
4.	Weight of raw coal, pounds per cu. ft.....	40.75
5.	Weight of residue, pounds per cu. ft.....	34.0

Gas 60°F., 30" Hg.

6.	Total gas generated, cubic feet.....	132
	Cubic feet per ton of raw coal.....	5860

Crude Oil

7a.	Weight of crude oil, pounds.....	3.73
	Pounds per ton of raw coal.....	165.5
7b.	Weight of light oil, pounds per ton of raw coal.....	5.0

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B.t.u.
Raw Coal	12.53	35.8	47.83	3.84	1.5	10,900
Smokeless Fuel	---	25.5	69.1	5.4	1.1	13,600

Gas Analysis, Percent by Volume, Air Free

Carbon dioxide, CO_2.....	26.9
Illuminants.....	4.7
Oxygen, O_2.....	---
Hydrogen, H_2.....	25.2
Carbon Monoxide CO.....	12.3
Methane, CH_4.....	27.6
Ethane, C_2H_6.....	3.3
Nitrogen, N_2.....	---
Heating Value, B.t.u. per cu. ft., 60°F.,30" Hg.	599
Weight of gas, pounds per 1000 cu. ft.....	62.5

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds		901
9.	Weight of total oil, pounds	170.5	
10.	Weight of gas, pounds	366	
11.	Weight of free moisture, pounds	251	
12.	Weight of water formed, pounds	113.5	
	Total		901

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds		1.77
14.	Weight of free moisture in the raw coal, pounds	0.125	
15.	Weight of water formed from the coal charged	0.057	
	Total	0.182	
16.	Weight of water in the wet crude oil, pounds	0.034	
	Difference	0.148	
17.	Actual weight of steam used, pounds		1.62
18.	Degrees of rise of retort temperature °C		482
19.	Actual weight of steam used, pounds per pound of coal per deg. C		.0034

Saturated Steam per Pound of Coal

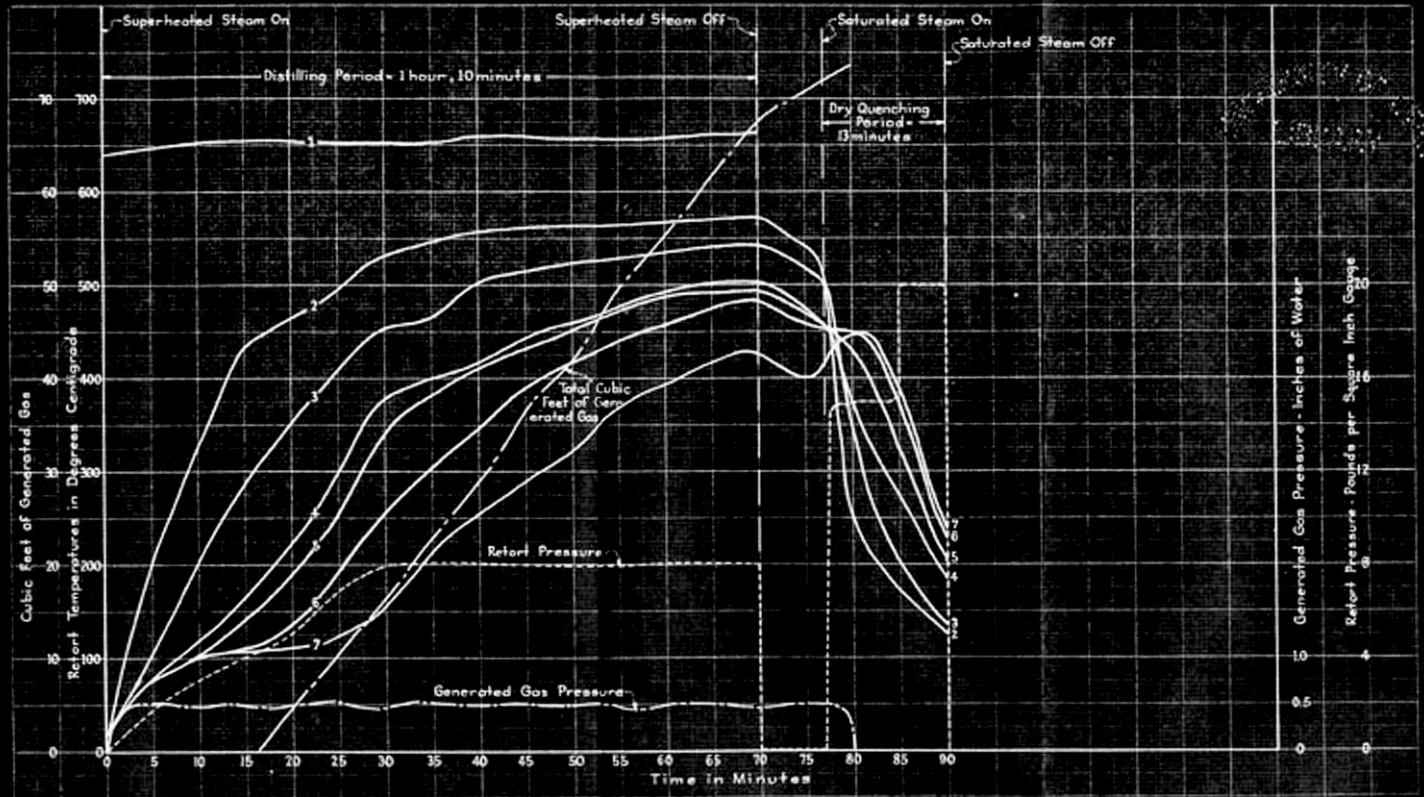
20.	Weight of saturated steam used, pounds		1.4
21.	Degrees of lowering of retort temperature °C		385
22.	Weight of saturated steam per pound of coal per deg. C		.0036

Heat Balance for One Retort, per Ton of Coal

		Thousand B. t. u.	Per cent of Total
23.	Total heat content of superheated steam entering retort	5620	100.00
24.	Heat given to the retort	289	5.14
25.	Heat given to the residue	191	3.40
26.	Heat in volatiles plus fixed gases	29	.52
27.	Heat content of steam leaving retort	4410	78.50
28.	Heat lost by radiation	17	.30
29.	Heat unaccounted for	684	12.14

Miscellaneous Data

30.	Time required for destructive distillation, hours	1.11
31.	Time required for dry quenching, hours	0.5



LOG OF PLANT OPERATION
for
DETAILED TEST No. 7
ROCK SPRINGS COAL, WYOMING

FIG. 13

April 19, 1934

LOW-TEMPERATURE CARBONIZATION PLANT

University of Utah

TABULATED RESULTS OF DETAILED TEST NO. 17

Date: April 19, 1934 Barometer: 25.5 in. of Hg.
Coal: Rock Springs
Size of Coal: -1½ to -3/4" Superheated Steam Temp. 650°C.

Coal and Residue

1.	Weight of raw coal charged, pounds.....	45
2.	Weight of residue from the retort, pounds...	29.5
3.	Loss in weight, pounds 15.5, per cent of total 34.4, pounds per ton of raw coal....	689
4.	Weight of raw coal, pounds per cu. ft.....	40.5
5.	Weight of residue, pounds per cu. ft.....	23.25

Gas, 60°F., 30" Hg.

6.	Total gas generated, cubic feet.....	61.8
	Cubic feet per ton of raw coal.....	2750

Crude Oil

7a.	Weight of crude oil, pounds.....	5.63
	Pounds per ton of raw coal.....	250
7b.	Weight of light oil, pounds per ton of raw coal.....	5

Proximate Analyses of Raw Coal and Smokeless Fuel, Percent by Weight

	Moisture	Volatiles	Fixed Carbon	Ash	Sulphur	B. t. u.
Raw Coal	2.2	40.5	51.22	5.08	0.96	13,120
Smokeless Fuel	---	16.3	78.5	5.2	0.68	13,560

Gas Analysis, Percent by Volume

Carbon dioxide, $C O_2$.....	12.6
Illuminants.....	6.6
Oxygen, O_2.....	---
Hydrogen, H_2.....	21.54
Carbon Monoxide C O.....	14.6
Methane, $C H_4$.....	35.75
Ethane, $C_2 H_6$.....	3.27
Nitrogen, N_2.....	5.64
Heating Value, B.t.u. per cu. ft., 60°F., 30" Hg.	740
Weight of gas, pounds per 1000 cu. ft.....	53.9

Mass Balance per Ton of Raw Coal

8.	Loss in weight of coal, pounds.....		689
9.	Weight of total oil, pounds.....	255	
10.	Weight of gas, pounds.....	148	
11.	Weight of free moisture, pounds.....	44	
12.	Weight of water formed, pounds.....	242	
		Total...	689

Superheated Steam per Pound of Coal

13.	Apparent weight of steam used, pounds.....		1.95
14.	Weight of free moisture in the raw coal, pounds.....	.022	
15.	Weight of water formed from the coal charged	.121	
	Total.....	.143	
16.	Weight of water in the wet crude oil, pounds	.025	
	Difference.	.118	
17.	Actual weight of steam used, pounds.....		1.83
18.	Degrees of rise of retort temperature °C.....		499
19.	Actual weight of steam used, pounds per pound of coal per deg. C.....		.0037

Saturated Steam per Pound of Coal

20.	Weight of saturated steam used, pounds.....		1.35
21.	Degrees of lowering of retort temperature °C.....		361
22.	Weight of saturated steam per pound of coal per deg. C.....		.0037

Heat Balance for One Retort, per Ton of Coal

		Thousand B. t. u.	Per cent of Total
23.	Total heat content of superheated steam entering retort.....	6060	100.00
24.	Heat given to the retort.....	300	4.95
25.	Heat given to the residue.....	236	3.89
26.	Heat in volatiles plus fixed gases..	41	.68
27.	Heat content of steam leaving retort	4910	81.02
28.	Heat lost by radiation.....	17	.28
29.	Heat unaccounted for.....	556	9.18

Miscellaneous Data

30.	Time required for destructive distillation, hours.....	1.17
31.	Time required for dry quenching, hours.....	.22

DISCUSSION OF LOGS OF PLANT OPERATION

The seven detailed tests were made, as is shown by Figures 7 to 13 inclusive, using superheated steam at three different temperatures in distilling three different coals. It will be seen by reference to these figures that, in general, the curves representing retort temperatures are all of the same characteristic shape. There are, however, several typical variations in these curves that are interesting to analyze.

Figures 7, 8, and 9, which are curves for Tests 1, 2, and 3 made on Aberdeen coal, show clearly the effect of superheated steam temperature on the length of the distilling period and the dry-quenching period. The distilling period of Test No. 1, using steam at 538°C, was thirty three minutes minutes longer than that of Test No. 2 using steam at 625°C, and forty one minutes longer that Test No. 3 using steam at 730°C. The dry-quenching periods are, however, nearly identical in length. Of course, the rate of steam flow, indicated by the retort pressure, during the two periods will affect the lengths of the periods, especially the dry-quenching period when saturated steam is used. The retort pressure curve during these three tests are all similar and hence it may be concluded that superheated steam temperature has very little effect upon the length of the dry-quenching period. The curves of Tests 4, 5, and 6, made on Grass Creek coal, Figures 10, 11, and 12, are further proof of this deduction since the dry-quench-

ing period of Test No. 4 in which saturated steam at 20 pounds per sq. in. constant pressure was used is four minutes shorter than thqn that of Test No. 5 using a pressure decreasing fron 20 pounds per sq. in., and 19 minutes shorter than that of Test No. 6 using a pressure of 15 pound per sq. inch. The distilling periods of these tests show the same variation with superheated steam temperature as those of the tests of Aberdeen coal.

Comparing the tests made on Aberdeen coal, Figures 7, 8, and 9, with those made on Grass Creek coal, Figures 10, 11, and 12, it will be seen from the curves that the ordinate intercepted between the thermocouples number 2 and 7, during the dry-quenching period of the latter tests, is shorter than a corresponding intercept on the curves of the Aberdeen tests. It will be noted, however, that the length of the dry-quenching periods of the Aberdeen tests are longer and hence it is reasonable to assume that both coals would behave much alike if subjected to the same rate of cooling.

In all the tests the temperature of the lower zone of the retort, indicated by thermocouples 4, 5, 6, and 7, did not begin to rise above 100°C for some 15 or 20 minutes after the distillation was begun. This is in accordance with Parr's statement quoted on page 41 of this work. This temperature lag is produced by the presence of water in the coal, and the temperature will not rise higher until the water is driven out. As soon as the moisture is driven out of the coal the rise of temperature is rapid, the rate of rise being aided by the exothermic property of our Utah coals.

It has been shown that this exothermic heat amounts to 27 to 45 B. t. u. per pound of coal. In processing coal by the method used in this study the exothermic or internal heat is utilized within the distilling range of temperature to augment the useful (distilling) heat of the superheated steam. A study of the logs will show how the temperature curves cross over eachother during the dry- quenching because of the heat exchange taking place in the coal charge. Also, it will be observed that the temperatures increase for a while in the lower part of the coal mass during the dry-quenching operation. The transfer of this 'high temperature' heat in the upper part of the coal charge to the lower part of the charge, whereby it accomplishes useful work, is a unique feature of this way of treating our Utah coals, and it serves to reduce the amount of superheated steam required. It may be concluded that this heat saving step will be greatly enhanced in distilling large batches of coal in large diameter retorts wherein the retort surface (the radiating area) is a much smaller heat-dissipating factor than in the retort used in the present study. Also in larger batches of coal the available heat stored in the residue is a much larger percentage of the total heat required.

DISCUSSION OF RESULTS OF DETAILED TESTS

As is to be expected, the yield of smokeless fuel decreases with increase in the distilling temperature because more of the volatile matter in the raw coal is driven off. On the other hand, the yield of artifical gas is increased with increase in the distilling temperature, but has a lower heating value. It is interesting to note that the greatest yield of oil was obtained when the coal was distilled at 650 °C.

The heat balance shows that 75 to 80 per cent of the heat supplied leaves the retort in the steam and volatiles. Important economies in steam comsumption are obtained, (1) by preheating the coal, (2) by using maximum steam temperature consistent with the optimum character and yield of the products (650°C.), (3) by using physically dry coal, (4) by utilizing the heat stored in the top portion of the coal charge to distill by transfer of its heat to the lower portion of the coal charge, (5) by reducing the heat absorption in the walls of the retort by using a retort covering of low conductivity and heat capacity, (6) by reducing radiation losses, (7) by using the sensible heat of the coal residue to preheat the new coal, (8) by condensing the issuing steam and oil vapors in an evaporator and using the new steam generated to dry-quench

and preheat other new coal charges, (9) and by using very tall retorts full of properly sized coal. There are good evidences that with the use of three or more retorts as a unit, the distilling, preheating and dry-quenching can be carried on simultaneously, thereby effecting distinct heat economies. In this manner, it is certain that a pound of coal can be distilled with less than one pound of superheated steam.

From the analyses of the smokeless fuel and the raw coal, it can be seen that the processed coal has approximately the same heating value as the raw coal, that its fixed carbon content is increased, that it contains no moisture, and that its ash content varies from 5 to 9 per cent. From this aspect, then, the smokeless fuel should be of considerable value.

Figure 14 shows typical Utah coal lumps both in the raw and processed states. In the center of the picture lumps of smokeless fuel are shown which have been produced while distilling without controlled pressure. It will be noted that these lumps have expanded, are full of cracks and are friable. At the right of the picture are shown lumps of solid smokeless fuel produced in this study. These lumps were produced under controlled pressure and it will be noted that the product is dense, substantially free of cracks, and is a fairly hard product.

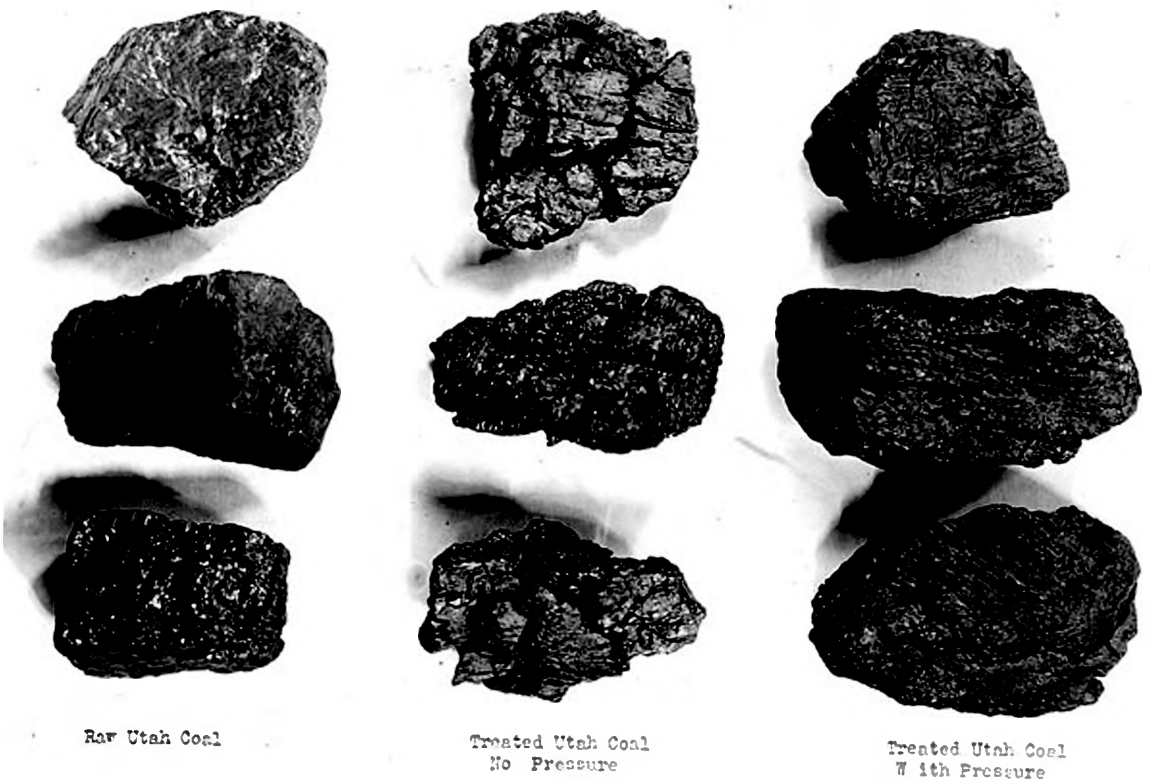


Fig. 14. Lumps of Raw and Processed Utah Coal

SAMPLE CALCULATIONS FOR DETAILED TEST NO. I.

The following information is presented to show the basis upon which the tabulated results and the figures representing the heat balance for the retort were calculated. The numbers of the items appearing below correspond to similar numbers presented on the tabulated result sheet. Items not listed are self-explanatory.

Mass Balance per ton of Raw Coal.

10. Weight of Gas.

This is the product of the total gas generated in cubic feet per ton and the density of the gas at standard conditions, (60° F. and 30" Hg.), which is,

$$1555 \times .073 = 113.5 \text{ lbs.}$$

The density of the gas was calculated by adding the multiples of the percentage of each constituent and its specific density. The specific density of the illuminants was determined by assuming that they are composed only of ethylene and benzene.

11. Weight of free moisture, pounds.

This is the product of the per cent moisture of the raw coal and the number of pounds in a ton, which is,

$$\frac{3.2}{100} \times 2000 = 64 \text{ lbs.}$$

12. Weight of water formed, pounds.

This is equal to the difference between the loss in weight of coal and the sum of the weights of total oil, gas, and free moisture, which is,

552 - (259.3 + 113.5 + 64) = 115.2 lbs.

Superheated Steam per Pound of Coal

13. Apparent weight of steam used, pounds.

This is the measured weight of steam condensate collected during the time that superheated steam was used.

16. Weight of water in the wet crude oil, pounds.

This is the weight of water, per pound of raw coal, contained in the wet crude oil as it came from the condenser and which weight was obtained by debydrating the oil.

17. Actual weight of steam used, pounds.

This is the sum of the apparent weight of steam used and the weight of the water in the wet crude oil less the sum of the weights of free moisture in, and water formed from, the raw coal, which is,

2.73 + 0.018 - (0.032 + 0.058) = 2.66 lbs.

18. Degrees rise of retort temperature - ^{o}C.

This is the difference between the average of the retort thermocouple readings at the end and at the beginning of the distilling period, which is,

450 - 13.5 = 436.5^{o} C.

19. Actual weight of steam used, pounds per pound of coal per deg. C.

This is equal to the actual weight of steam used per pound of coal divided by the degrees rise of retort temperature, which is,

$$\frac{2.66}{436.5} = 0.0061$$

Saturated Steam per Pound of Coal.

21. Degrees lowering of retort temperature.

This is the difference between the average of the retort thermocouple readings at the end of the distilling period and at the end of the dry-quenching period, which is,

$$450 - 196.6 = 253.4$$

22. Weight of saturated steam per pound of coal per deg. C.

This is equal to the weight of saturated steam used divided by the degrees rise of retort temperature, which is,

$$\frac{1.262}{253.4} = 0.0049$$

Heat Balance for One Retort, per Ton of Coal.

23. Total heat content of superheated steam entering retort.

Since the published steam tables do not give the properties of superheated steam above 1000 degrees Fahrenheit, it was necessary to substitute in Goodenough's empirical equation:

$$H_S = 0.320\ T_a + 0.000063\ T_s^2 - \frac{23.583}{T_s} - \frac{C_3 P\ (1+0.0342P^{\frac{1}{2}})}{T_s^4}$$

$$0.00333P + 948.7$$

in which

H_s = total heat of one pound of superheated steam above 32 deg. F.

T_s = superheated steam temperature - deg. F. absolute.

C_3 = a constant, the logarithm of which is 10.7915

P = pressure of superheated steam, pounds per square inch, absolute.

The superheated steam temperature corresponding to 538.8° C., the average temperature of the superheated steam during the distilling period, was:

T_s = 1002 + 460 = 1462° F. absolute.

The average pressure was:

$$P = 5.13 + \frac{25.61}{2.04} = 5.13 + 12.54 = 17.67 \text{ lb. per square inch absolute.}$$

Substituting the above values in Goodenough's equation gives the total heat of one pound of superheated steam as being 1550.9 B.T.U.

The total heat of the superheated steam entering the retort is the product of the heat content of one pound of steam and the pounds of steam used per ton of raw coal, which is,

1550.9 x 2.66 x 2000 = 8,260,000 B.T.U.

24. Heat given to retort.

This is equal to the product of the specific heat of the retort shell and the weight of the sheet iron plus the product of the specific heat

of the retort caps and the weight of the caps, each product being multiplied by the degrees rise of retort temperature in deg. F., which is,

$$0.1228 \times 43 \times 786 = 4150$$
$$0.117 \times 19 \times 786 = 1750$$
$$5900 \text{ B.T.U. per test charge of coal.}$$

Converting this to heat per ton of coal we have:

$$\frac{5900}{44.75} \times 2000 = 263{,}000 \text{ B.T.U.}$$

25. Heat given to residue.

This is equal to the product of the weight of the residue, the degrees rise of retort temperature in deg. F., and the specific heat of the residue, which is, per ton of coal,

$$29.75 \times 0.2 \times 786 \times \frac{2000}{44.75} = 209{,}000$$

26. Heat in volatiles plus fixed gases.

This quantity is equal to the product of the weight of the volatiles and fixed gases, the specific heat of the two, and the temperature difference between the average temperature of the vapor as it left the retort during the distilling period and the average temperature of the coal before distilling was begun, which is:

$$372.8 \times 0.3 \times 406 = 47{,}500 \text{ B.T.U.}$$

27. Heat content of the steam leaving the retort.

This is the product of the heat content of

one pound of steam at the average temperature and pressure of the vapor leaving the retort during the distilling period and the sum of actual weight of superheated steam used, the weight of free moisture in the coal, and the weight of water formed from the coal. This gives:

1268 (2.66+ 0.09) x 2000 = 6,970,000 B.T.U.

28. Heat lost by radiation.

This is the sum of the heat lost by radiation from the lower retort cap and the heat lost through the retort insulation during the distilling period.

The equation for radiation loss is

$$q = 0.147 (T_1^4 - T_2^4) A$$

where:

q = heat radiated - B.T.U. per hour.

T_1 = absolute temperature of retort cap. $^{o}F.$

T_2 = absolute temperature of room. $^{o}F.$

A = area of cap, sq. ft. = 144 sq. inch

Substitution gives:

$$q = 0.147 \left(\left[\frac{760}{100}\right]^4 - \left[\frac{530}{100}\right]^4 \right) = 374 \text{ B.T.U.}$$

The heat lost by conduction through the retort insulation, which heat is lost by radiation and conviction from the insulation surface is given by the equation:

$$h = \frac{(t - t_1) K}{r_1 \log_e \frac{R}{r_1}}$$

where h = heat conducted in B.T.U. per hour per sq. foot.

r_1 = inside radius of insulation, = 2.5 in.

R = outside radius of insulation, = 8.75 in.

K = constant = 1.4 for this type of material.

t = temperature at inside surface of insulation.

t_1 = temperature at outside surface of insulation.

Assuming a maximum t_1 of 100° F. we have, for t = 706° F. (average retort temperature during distilling period):

$$h = \frac{(706-100)\ 1.4}{2.5 \log_e \frac{8.75}{2.5}} = 271 \text{ B.T.U. per sq. ft. per hour.}$$

The area of the insulation surface is:

$$A = \frac{3.14 \times 17.5}{12} \times 8.5 = 39 \text{ square feet}$$

Hence the heat lost per hour equals

$$39 \times 271 = 10{,}610 \text{ B.T.U.}$$

The total radiation loss are then:

$$10610 + 374 = 10984 \text{ B.T.U. per hour.}$$

And the losses for the distilling period of 1.55 hours are:

$$1.55 \times 10984 = 16500 \text{ B.T.U.}$$

29 Heat unaccounted for.

This is the difference between the heat of the superheated steam entering the retort and the sum of the items numbered 24 to 28 inclusive. It includes all heat that could not be calculated be-

cause of small accumulated errors in temperature observation and weight determinations.

Substitution of the values in thousands of B.T.U. gives:

$$8260 - (263 + 209 + 46 + 6970 + 17) = 755 \text{ B.T.U.}$$

PRODUCTS FROM UTAH COAL OIL

Analyses of the crude oils from the different coals treated in this study proved them to be very similar. Consequently the crude oil from a representative Utah coal was used as a crude oil supply for an investigation of the refinability of this oil.

Gasoline was the principal oil porduct sought although kerosene, fuel oil, fuel gas and cresylic acid were also produced and their quantities measured. A 2-gallon pressure cracking still was provided with a thermocouple well, pressure gauge, a water-cooled pressure condenser, and a pressure regulating needle valve. A charge of 1.5 gallons of the crude oil was first dehydrated under pressure and then cracked at 775° F. - 800° F. and 125 pounds pressure, the distillation requiring about 3 hours to complete.

This crude oil is solid at room temperatures because of the high content of waxes, resins and high-boiling hydrocarbons. The distillation yielded 65 per cent of pressure distillate, also carbon and gas. About 110 pounds of carbon (ashless coke) were produced per barrel of the crude oil cracked, also approximately 850 cubic feet of 1350 - B.t.u. gas. The pressure distillate was fractionated at 205° C. and 253° C. at 640 mm. pressure,

thereby forming three fractions, namely, - gasoline, kerosene and fuel oil. All fractions were washed with 10- per cent sodium hydroxide solution to remove the tar acids which were subsequently released from solution by neutralizing with sulphuric acid. The gasoline was then agitated with concentrated sulphuric acid in three successive treatments, after which it was neutralized and distilled. This gave a yield of 20 per cent of light yellow gasoline which was color-stable and of the proper volatility for motor use. The kerosene was similarly refined but with less acid.

The yields of the oil products were as follows:

Product	Per cent of crude	Gallons per ton of coal
Gasoline	18	5.75
Kerosene	18	5.75
Fuel Oil	20	6.40
Cresylic Acid	3.1	1.0

Previous studies made at the University in 1932 by Kinney, Burton and Karrick, gave approximately the same results.

BURNING CHARACTERISTICS OF THE SMOKELESS FUEL

Throughout this investigation a large number of expirements were made to compare the ignitability and burning properties of the semi-cokes produced, with raw coal, metallurgical coke, petroleum coke, cannel coal and anthracite.

This study was accomplished in part by placing equal sized pieces of the different fuels into separate electrically heated muffles in the presence of air and causing all to heat up simultaneously at controlled rates until combustion took place. The device proved to be an excellent way of obtaining comparative data on the kindling temperatures, smokelessness of combustion, rate of burning, flaming properties, physical properties of the various fuels while burning, and etc. It may be briefly stated that the semi-coke kindled as readily as the raw coal and exhibited an attractive but smokeless flame, also that it did not disintegrate while burning which was not the case with any of the raw coals. The metallurgical coke was hardest to ignite, the anthracite next, and while the petroleum or creosote cokes ignited fairly readily, both were observed to yield an oily smoke when starting to burn.

Further studies were made of the combustibility

(chemical activity) of the semi-coke by contacting it with highly heated steam and noting the rate and temperature at which water gas was formed. This experiments were accomplished in the carbonizing retort and it was noted that water gas formed rapidly when the superheated steam was about 1250° F.

The unusual capacity of this semi-coke to ignite easily and burn readily, was demonstrated in a series of tests made in standard house-heating devices. The services of the City Smoke Engineer were obtained to secure for this study a hot-blast heating stove and a cook stove, which are typical of the types used to heat 12,000 of the small dwellings in Salt Lake City. Figure 15 [b] shows these devices and a fireplace which were installed in the fuels laboratory for this study. The three appliances were equipped with all the necessary instruments to measure draft, gas temperatures, smoke or fly-ash in the gases, to take gas samples, etc. A series of heating studies were then made to compare the semi-coke with the raw coal, and in all instances attempts were made to duplicate average residence firing technique. Table XIII is a summary of the results obtained.

(a) Pile of Smokeless Fuel Used for Heating Appliance Studies

(b) View of the Heating Appliances Tested

Fig. 15

TABLE X111

SUMMARY OF HEATING EFFICIENCIES WITH A HEATING STOVE, AND COOK STOVE AND FIRE PLACE

	Heating Stove		Cook Stove		Fireplace	
Total heat involved	Coke	Coal	Coke	Coal	Coke	Coal
Heat input, %	100	100	100	100	100	100
Stack gas losses, %	29.5	39.4	72.6	66.1	66.4	87.1
Effective heat, %	70.5	60.6	28.4	33.9	33.6	12.9

It will be noted that the semi-coke gave 1/6 more heat than the coal in the heating stove, and nearly three times as much heat as the raw coal in the fireplace, but the coal gave 1/5 more heat in the cook stove. It is believed that the heating stove results are indicative of results to be expected in residence use of the two fuels. The cook stove permitted a great amount of air leakage through the warped lids of the stove and the figures are not necessarily duplicable. The writer believes that the semi-coke will also give higher efficiency in similar cook stoves in good repair. Undoubtedly the fireplace will give considerably higher heating efficiencies with both fuels by proper manipulation of the dampers and drafts. This was not done as it was the purpose in these tests to burn both fuels under identical draft conditions which are typical of coal com-

bustion as applied in the average residence. The heat-balance calculations presented above were made by the methods described in "Fuels and Their Combustion" by Haslam and Russell.

A portion of the stack gases were metered and filtered in each of the above heating appliance tests with semi-coke and coal, and the results are shown in Table XlV below:

TABLE XlV

MATERIAL IN STACK GASES FROM COAL --
BURNING APPLIANCES USING SEMI-COKE AND COAL.

	Material in stack gases per ton of fuel.	
Appliance	Semi-coke	Coal
Heating Stove	0.35 lbs.	37.5 lbs.
Cooking Stove	27.8 "	37.9 "
Fireplace	0.375 "	47.4 "

From the above data it will be noted that the collected soot, tar, carbon dust and ash were many times greater from the burning of the raw coal. In the case of the cook stove, however, it appeared that the excessive amount of solid particles obtained while burning the semi-coke were derived from fine coke dust in the charge or from accumulations of dust from previous uses of the stove. The filters were in no case even discolored by tar or soot while burning the

semi-coke, but during the heating stove tests with raw coal the filter was completely saturated with sticky tar and soot. While burning raw coal in the cook stove and fireplace the filters were heavily coated with a flocculent soot but very little tar was evident. It can be said with assurance that the clean and efficient fire obtained from burning the semi-coke in these widely used residence heating appliances, and its ready ignition and response to draft changes, argues strongly for its widespread use in our cities.

The results of these house heating appliance studies agree very well with the results of similar studies made in 1926 by L. C. Karrick at the Pittsburgh station of the U. S. Bureau of Mines. In the latter investigation of Utah coals, large quantities of low-temperature coke was made and its burning characteristics determined in comparison with Utah coal and other fuels in a popular form of domestic furnace. The smokeless fuel gave between 10 and 30 per cent higher heating efficiency than the raw Utah coal. The fuel also responded quickly to draft changes and produced no smoke whatsoever.

CONCLUSIONS AND ECONOMICS

The urgent necessity for the elimination of smoke from the atmosphere of our cities was brought to the reader's attention in the opening pages of this thesis. Furthermore, the value of a solid smokeless fuel suited to use in our domestid heating appliances, and which can be produced from Utah coals, has been pointed out.

After making a comprehensive investigation of the broad subject of low temperature carbonization, and especially as it applies to the treatment of the Rocky Mountain coals primarily for the production of smokeless fuels, the conclusions based on our studies and those from the foremost authorities should now be presented in brief form for public study and application.

The studies made during the course of this investigation conclusively show that a solid smokeless fuel well suited to burning in our domestic coal-burning appliances can be easily produced from the greater portion of the coals of Utah and Wyoming. Many combustion studies were made with this processed fuel in a popular form of hot blast heater, in a cook stove and a fireplace. Also several sacks of the new fuel were distributed among interested local citizens for trial. In each instance the fuel ignited easily and burned without any trace of smoke. Only favorable comments were received from the many enthusiastic persons who saw this new fuel in use.

Proximate analyses of the semi-cokes show that their heating values are approximately equal to those of the raw

coal, and that the ash content never reached ten percent. Furthermore, these studies showed that ten to thirty percent more heat is made available through the use of the processed coal than is obtained by the use of the same amount of the raw high volatile coals.

The writer is firmly convinced that the solid fuel produced by the low temperature carbonization of Utah coals by the system employed in this work, is a suitable fuel which can be used in the present types of domestic coal burning equipment, and with satisfaction, and thereby eliminate the cities' deplorable smoke nuisance. This is a tardy development in our progressive scientific era considering the extent and the thoroughness of the investigations that have been made on our Utah coals.

A widespread market for the smokeless fuels at prices within the reach of every pocket book should be readily obtained. Gentry [24] says that "80 percent of the entire coal consumption of the United States can be substituted by processed solid fuel".

As has been previously described, the crude oil obtained from the low temperature carbonization of Utah coals is well suited to the cracking and refining into gasoline by present oil refining processes [38]. As a result, gasoline of quality equal to the best ethyl gasolines can be obtained. Also high grade kerosene, furnace oil, diesel oil, and road oil can be produced. Derivatives suitable for wood preservatives and insecticides can be made from the coal oils, also, according to Gentry, high grade lubricants. According to the work of the U. S. Bureau of Mines investigators, the resins in

some seams of Utah coals have the composition of Copal gum which is one of the principal ingredients used in the manufacture of nitrocellulose lacquers, and should find a good market.

This study of the destructive distillation of Utah coals has amply demonstrated that gas the equal of the imported natural gas in heating value can be formed simultaneously with the production of a good quality crude oil and a badly needed solid smokeless fuel. This coal gas should deliver more heat than natural gas, per heat unit contained, because of the greater amount of combined carbon and less dilution of the combustion gases with water vapor. The amount of gas generated while processing enough coal to provide Salt Lake's solid smokeless fuel would not exceed the present gas consumtion. Also the gasoline, road oil and other oil products would be a small part of the volume of petroleum products now imported into the state, and therefore should find a ready and enthusiastic market.

F. R. Wadleigh [37] has said that:

> "The time may come, and is coming, when no bituminous coal will be burned in its raw state. Leading chemists and engineers have many time expressed the opinion that the use of coal 'as is' should not and will not be tolerated much longer; that such use is an economic waste of our raw material that is sure to be eliminated in the not-too-distant future, when we have reached the full realization of the age-old maxim, that waste makes want".

Some highly trained engineers of Utah have fearlessly advocated the immediate erection of a commercial scale pilot plant to treat our coals along the lines of processes worked out in the State and Federal Government's engineering and econ-

omic studies.

On October 28, 1932 a detailed report (22) with plant estimates and blue prints was formally presented by Dean R. B. Ketchum of the School of Mines and Engineering, to Chairman W. R. Wallace of the Joint Smoke-Abatement Committee of the Salt Lake Chamber of Commerce. This report advocates the immediate erection of a commercial-scale pilot plant, and says,-"----- we recommend that steps be taken to finance such a plant as is herewith described." The figures in the report show that this 30-ton plant and oil refinery will show a profit over and above all operating and capital costs, and the products will sell at present prices for like commodities. Obviously, a large commercial plant treating 1,000 or more tons of coal per day will be able to embody many economies in investment and operating expenses. For instance, the process steam cost would be very low for the reason that this steam would be derived from off-peak boiler capacity, or steam bled from turbines, in central steam power plants. Fuel for r raising steam and superheating would likewise be reduced in cost.

During the course of the past two years work in coal processing, the writer has learned that the merit of low-temperature carbonization of coal in Utah, is made to appear as a very controversial subject. The chief criticisms voiced are, (1) that a commercial sized plant operating on the principles worked out by Mr. L. C. Karrick and associates in the government service will not be successful because of mechanical troubles, reference of plausible nature being made to failures of other plants which treated other coals

while using other processes and under different economic conditions than those existing in Utah, and (2) that the markets for the coal products described in this thesis are limited, and therefore, such a venture is economically unsound.

The writer finds that Mr. Karrick's coal treating processes are based on scientifically sound principles, and has observed that no difficulties whatsoever were encountered with the successful mechanical operation of the plant used for this investigation. It is interesting to note that no changes in the design of the plant were necessary in order for it to work smoothly and efficiently.

Many years of intensive work done at the public's expense have been utilized by the State and Federal Governments while developing the principles on which the processes patented by Mr. Karrick are based. That such information and scientific developments should be placed to public advantage and community enrichment, can not be disputed. The smoke nuisance which costs the people of Salt Lake City approximately $ 10,000 daily by damage to household effects, is certainly a disgrace to our present scientific and ' civilized' social order. In view of these facts, it is the writer's belief that the Utah scientist and engineer should now accept the challenge and immediately take steps to solve this great menace to normal domestic and industrial progress. It is also the duty of our citizens to support the development of a coal-products industry in Utah. In this connection the writer greatfully acknowledges the valuable support of this plan by leading women of Salt Lake City who have materially aided the creation

of a University Research Foundation for the purpose of carrying on the development of a coal-products industry, also for their present work in connection with F. E. R. A. coal-treating project to be placed in operation at the University.

Therefore, the writer holds the opinion that a commercial size plant of a few units should now be built and operated as a 'ward' of a public spirited organization in Utah. The Utah Research Foundation which was initiated by Mr. Karrick for the endowment of the University of Utah and to bring other public benefits, should be the logical organization to father this movement. When such a plant has operated for a reasonable period it will then be time for those who oppose such a development to present facts and figures, if any, in support of the claim that such enterprise is not economically feasible.

It has been said that: (39)

> "The perfect solution of the city's smoke problem would be attained by a combination of an adequate and permanent source of rich gas, a suitable solid smokeless fuel, and a furnace oil, at prices within reach of the poor man. The sources should be within the state and by their development, production, and supply to the consumer, all state and city industries in anywise affected should be benefitted. There should be no need for added investment to the home-owner for new equipment in order that the smokeless fuels will be exclusively used in the city."

APPENDIX 1

COAL

It has been said many times by many people that "We never miss the water until the well runs dry". As old as this saying is, the idea that it conveys can still be applied today. For instance, when we put a shovel full of coal into the combustion chambers of our heating equipment, we seldom consider that we have there the conserved and concentrated solar energy of many millions of years ago. We do not take cognizance of the fact that coal, which still is man's most important single source of energy, is the direct result of the processes of Mother Nature which began long before man was destined to put in an appearance on this earth, and which required many long years to complete. In short, to most of us, coal is just a black, dirty earth product which is easily secured for the many uses that man claims for it; and our interest in it begins and ends right there.

It is with this idea in mind, that a discussion of coal in relation to its origin, geography, uses and production, together with some interesting auxiliary information, was included in this thesis.

Origin. After years of extensive research work carried on by the United States Government and others, it is now well established that coal deposits are of organic

or vegetable origin. David White (40) writing in 1913, says, " The fact is almost universally accepted that beds of coal represent accumulations of vegetal matter in varying stages of preservation, with as a rule, very small proportions of the remains of animal life. Mingled with the organic substances are different inorganic mineral sediments, which, together with the mineral matter originally contained in the plants themselves, constitute the 'ash' of the coal. The examination of coal shows that the kinds of ingredient plants range all the way from algae and fungi to large trees of various orders, and that these in turn vary in their own groups according to the depth and the nature of the water in which they grew and according to the other conditions of growth, such as moisture, temperature, soil, light, climate, and the competition of individuals. "

The accumulation of vegetal matter took place in damp lowlands and bogs. There, with the exclusion of air by water, a slow process of disintegration took place. The top layer of the bogs consisted (41) of living plants; below this were dead plants; and finally, at the bottom was a spongy, jelly-like mass. Each of these layers gradually changed into the next. Thus according to Gentry (24), " the vegetable tissue, consisting mainly of cellulose, decomposed with the liberation of the oxides of carbon, marsh gas, and water, to form the material known as peat. As the

bottom lands sank below the surface of the water and sedimentary deposits built up, a pressure developed which rendered the peat deposits more compact and consolidated, thus forming the lignites and subbituminous coals. The internal forces of the earth became active at that stage and the sedimentary rocks above and below the lignite deposits were violently thrown into folds, developing additional pressure with the generation of heat. The result of this upheaval and folding was the further consolidation of the mass and its transformation into bituminous coal. The remaining metamorphosis into anthracite is said to have been brought about by further excessive pressure and by the cracking of the rock folds to permit the escape of entrapped hydrocarbons, evolved from the carbonaceous material."

According to Heinrich and Ries [42], the chemical representation of the various transformations is as follows:

$$5\ C_6H_{10}O_5 \rightarrow 6\ CO_2 + CO + 3\ CH_4 + 8\ H_2O + C_{20}H_{22}O_4$$

Cellulose — Lignite

$$6\ C_6H_{10}O_5 \rightarrow 8\ CO_2 + CO + 5\ CH_4 + 10\ H_2O + C_{22}H_{20}O$$

Cellulose — Bituminous

$$7\ C_6H_{10}O_5 \rightarrow 8\ CO_2 + 4\ CH_4 + 19\ H_2O + C_{30}H_{16}O$$

Cellulose — Semi-bituminous

In these equations CO_2 represents carbon dioxide; CO

carbon monoxide; CH_4 methane or marsh gas; and H_2O water.

The two outstanding epochs of geologic time[43] for the formation of coal are the Pennsylvanian and Upper Cretacious; which date back to some 240,000,000 years and 95,000,000 years respectively. In general, the Pennsylvanian coals of the United States occur East of the 100th meridian; the Upper Cretacious coals from the 100th to the 115th meridian, and the coals of the Tertiary period between the 120th meridian and the Pacific Ocean. An exception to this geologic distribution is a large area of Tertiary lignites in the Gulf States and a small area of Trianic coals in Virginia and North Carolina.

It is interesting to note what some studies concerning the time required for the formation of coal show. Ashley[44] estimates that one foot of coal would form in 300 years from about 37 feet of uncompressed peat. This would mean then, that the 84 foot seam of subbituminous coal at Adaville, Uinta County, Wyoming, required some 24,000 years for its formation.

Classification: Coals and allied substances have been variously classified,[13] according to:

1. Oxygen-hydrogen ratio, or Gruner's classification.
2. Fixed carbon and volatile combustible matter.
3. Fuel ratio, or the ratio of fixed carbon to the volatile combustible matter.
4. Calorific power.

5. Fixed carbon.

6. Total carbon

7. Hydrogen.

8. Carbon-hydrogen ratio, or the ratio of the total carbon to the hydrogen.

All of these classifications are more or less unsatisfactory because of their limited application [45] and the overlapping of the various groups.

The classification as devised by the United States Geological Survey [46] and adopted by the United States Bureau of Mines seems to be most widely used. This method classifies the coal according to the diagram presented by Figure 16. The word rank in this connection is used to designate "those differences in coal that are due to the progressive change from lignite to anthracite, a change marked by the loss of moisture, of oxygen, and of volatile matter." It must be remembered that there is no sharp line of demarcation between each succeeding rank, the difference being largely a matter of the percentage of fixed carbon and volatile content.

From Figure 16, the progressive changes which take place in the constitution of coal due to geologic aging can be clearly seen. The moisture content of the fuel reaches its maximum in the peats and decreases to a low-percentage in the anthracite. The volatile matter rises to a maximum in the bituminous coals, and then progressively decreases

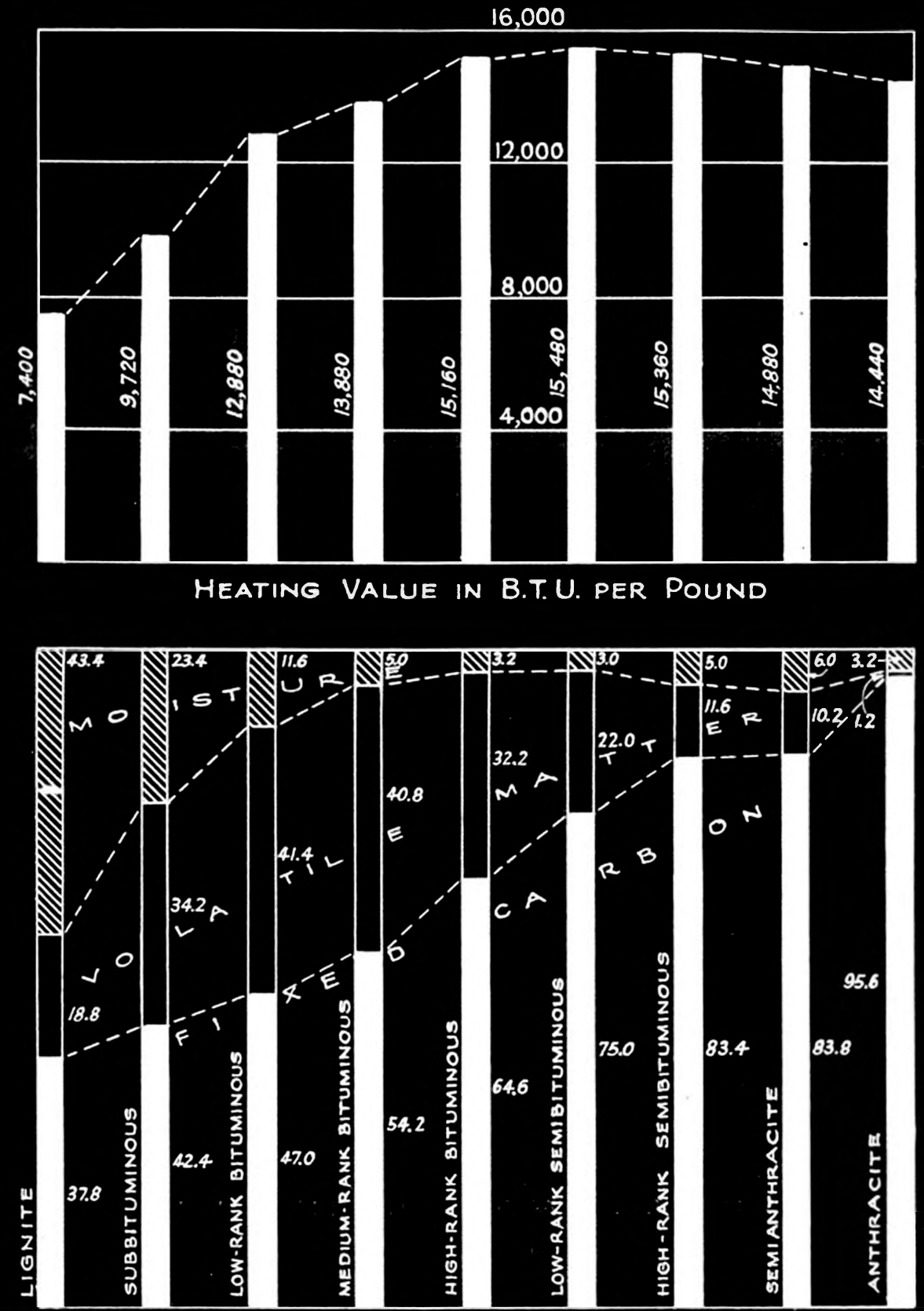


FIGURE 16

A DIAGRAM SHOWING THE CHEMICAL COMPOSITION AND HEATING VALUE OF THE SEVERAL RANKS OF COAL. ALL OF THE FIGURES GIVEN ARE CALCULATED ON THE ASH-FREE BASIS.

DATA TAKEN FROM U.S. GEOLOGICAL SURVEY · PROF. PAPER 100-A

with the aging. The fixed carbon, however, increases at an almost constant rate with the change from peat to anthracite. The heating value of the coal increases with the consolidation of the fuel, except for a slight decrease among the hard coals.

For a fundamental concept of the various classes of coal, M. R. Campbell (47) is quoted as follows:

Anthracite. Anthracite is generally well known, but in a systematic classification it is generally defined as a hard coal having a fuel ratio (fixed carbon divided by volatile matter) of not less than 10. Most of this coal comes from the anthracite fields of Eastern Pennsylvania, but small areas are known in some of the Western States.

Semi-anthracite. Semi-anthracite coal has a fuel ratio ranging from 6 or 7 to 10. There is only a small amount of this coal in the United States.

Semi-bituminous. Semi-bituminous coal is of great commercial importance, but is not widely distributed. Its fuel ratio ranges from 3 to 6 or 7. It is the best steam coal in the country, and some of it can be utilized in the manufacture of coke. The centers of production are the Pocahontas and New River fields of Virginia and West Virginia, Georges Creek field of Maryland, Windber field of Pennsylvania, and the western end of the Arkansas field in the vicinity of Fort Smith. Though small areas contain-

ing this grade of coal have been found in Washington and Colorado, the amount of such coal in these fields is small.

Bituminous. Bituminous coal is the most important grade in the country and includes most of the coals East of the Rocky Mountains. In the Western States there are large areas of bituminous coal, such as the Trinidad-Raton fields of Colorado and New Mexico; the Grand Hogback field of Colorado; the Book Cliffs field of Utah; the Rock Springs, Kemmerer, and Black Hills fields of Wyoming; the Great Falls fields of Montana; and many districts of Washington. This grade furnishes most of the coking coal of the country, and it is largely sold for steam raising and for domestic use.

Sub-bituminous. The term " sub-bituminous " has been adopted by the United States Geological Survey for what has generally been called " black lignite. " The latter term is objectionable, for the reason that the coal is not lignitic in the sense of being woody, and the use of the term seems to imply that the coal is little better than the brown, woody lignite of North Dakota, whereas many of the coals of this class closely approach the lowest grade of bituminous coal. In fact, it is extremely difficult to separate this class from the one below and the one above. It is generally distinguished from lignite

by its color and freedom from apparent woody texture and from bituminous coal by the slacking it undergoes when exposed to the weather. As the latter is an important difference in commercial use, it has been adopted by the Geological Survey as the criterion for the separation of subbituminous and bituminous coals.

Subbituminous coal is found in most of the western fields, being well known in the field about Boulder and Denver and in North Park, Colorado; Gallup, New Mexico; Hanna, Douglas, Sheridan, and Bighorn Basin, Wyoming; Red Lodge and Musselshell, Montana, and in many of the districts of Washington and Oregon.

Lignite. As used by the Geological Survey the term " lignite " is restricted to the coals that are distinctly brown and generally woody. They are intermediate in quality between peat and subbituminous coal. Lignite is abundant in the North in Eastern Montana and North Dakota and in the Northwest corner of South Dakota. In the South it is present in all of the Gulf States, but it has been developed commercially only in Texas.

Coal Reserves of the World. According to the latest estimates, the coal reserves of the world, by continents, are as follows:

America . . . . . 5,628 billions of tons (2,000) lbs.)

Asia 1,410

Europe 864

Oceania 188

Africa 64

Of the amount contained in the Americas, the United States claims 4,205 billions of tons, or 51 per cent of the total coal of the world.

Coal Fields of the United States. Coal is mined from 33 states in the United States. The various coal provinces are shown in their proper locations on the accompanying sketch map of the United States. (See Figure 17).

It is from the Appalachian district in the Eastern Coal Province that approximately 38 per cent of the country's bituminous coal is produced. A limited area of 480 square miles in Eastern Pennsylvania yields all of the anthracite* which is produced in this country. The combined fields of the Province mine about 71 per cent of the coal marketed annually.

The Interior Province is made up of the bituminous coal fields and regions near the Great Lakes, in the Mississippi Valley, and in Texas. Principal interest centers on the Illinois and Indiana coal fields which together produce 19 per cent of the nation's total output and rank next in importance to the Appalachian district.

Coal of the Gulf Province is of little commercial importance, it being mostly lignite and mined in onlya a few localities in Texas. The Northern Great Plains Pro-

COAL FIELDS OF THE UNITED STATES

FIGURE 17

vince contains coal of the same rank. Its largest coal-bearing area is the Fort Union region, lying in the Dakotas, Montana, and Wyoming. The lignite from this region is of poor quality and is, therefore, not extensively mined.

The coal of the Rocky Mountain Province ranges from lignite in North and South Dakota to small deposits of anthracite in Colorado, Utah and New Mexico. The leading producer for 1931 was Colorado, with Wyoming second, Utah third, and South Dakota last. The Rocky Mountain field contains a tremendous tonnage of coal which has been developed only on a relatively small scale. The combined production of the Rocky Mountain Province and the Northern Great Plain Province amounts to only 6 per cent yearly.

The Pacific Coast Province contains coal of low rank or poor quality in California and Oregon, but Washington yields suitable coal for industrial purposes.

Production of Coal in the United States. The history of coal discovery and production is given in the U.S.G.S. Mineral Resources Book of the United States for 1906, p. 578, as follows: "So far as is known, the first mention of the occurrence of coal in the United States is contained in the journal of Father Hennepin, a Jesuit missionary, who in 1679 recorded a "cole mine" on the Illinois River near the

---

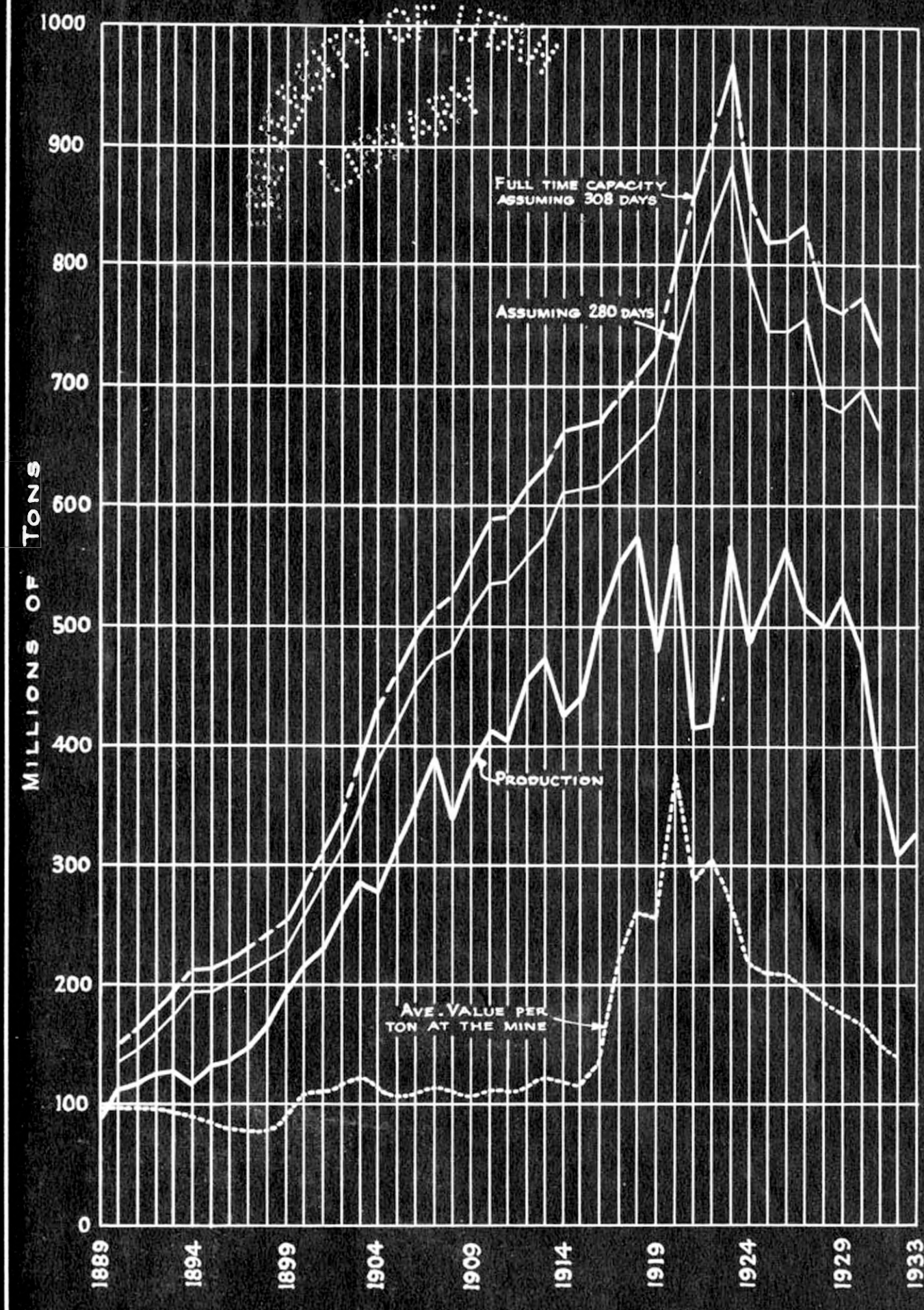
* In 1931 this amounted to 59,645,652 net tons.

present city of Ottawa, Illinois. The first actual mining of coal was in the Richmond basin, Virginia, about 70 years after Father Hennepin's discovery in Illinois, but the first records of production from Virginia mines were for the year 1822 when, according to one authority, 54,000 tons were mined. . . . . The mining of anthracite in Pennsylvania began about 1790 and it is said that in 1807, 55 tons were shipped to Columbia, Pennsylvania."

Because of the predominance of bituminous coal of varying ranks in the United States most of the production figures are given for this class of coal. Figure 18 shows the variation of the net tons of bituminous coal produced in this country during the period from 1889 to 1933 inclusive. Along with this is shown the variation of coal mine capacity and the average price per ton of coal at the mine. The curves are all self-explanatory. The general conclusions are that the annual production is now at the 1905 level; the average value per ton is about the same as it was in 1916; and finally that the capacity for production has always been greatly in excess of the demand.

Out of 1,230,000,000 net tons of coal produced in the world in 1932, the United States produced a total of 29 per cent. This represented a decrease of 42 per cent compared to the production of 1929.

The distribution of bituminous coal consuption and the importance of coal in supplying energy for the use of man



TREND OF BITUMINOUS COAL PRODUCTION AND COAL MINE CAPACITY IN THE UNITED STATES

FIGURE 18

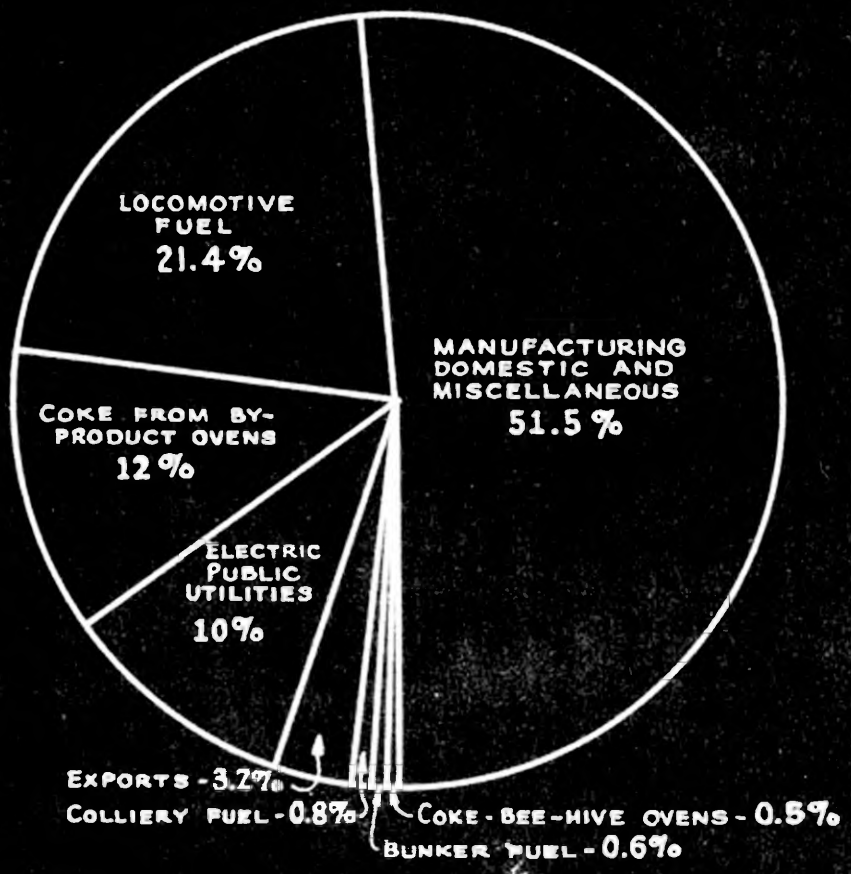
DATA FROM MINERAL RESOURCES OF U.S.

are shown by Figure 19. It is interesting to note that since 1913, the world has secured its energy at an ever increasing rate from water power, oil and gas, thus displacing coal. In 1931, 63.7 per cent of the energy consumed came from bituminous and anthracite coal; 21.2 per cent from oil and gas; 10.2 per cent from water power; and 4.9 per cent from lignite. Whereas, in 1913, the corresponding figures were: 84.4 percent; 7.1 per cent; 4.2 per cent; and 4.3 per cent. The competition of fuels is of no small consequence as is shown by these figures.

Coal Fields of Utah. Coal in Utah was discovered (48) in 1851 in the Colob-Kanab field near Cedar City. The Wales mine in Sanpete County was opened in 1855 and has the distinction of being the oldest coal mine in the state. The first mine in Carbon County was the Winter-quarters mine which was established in 1878.

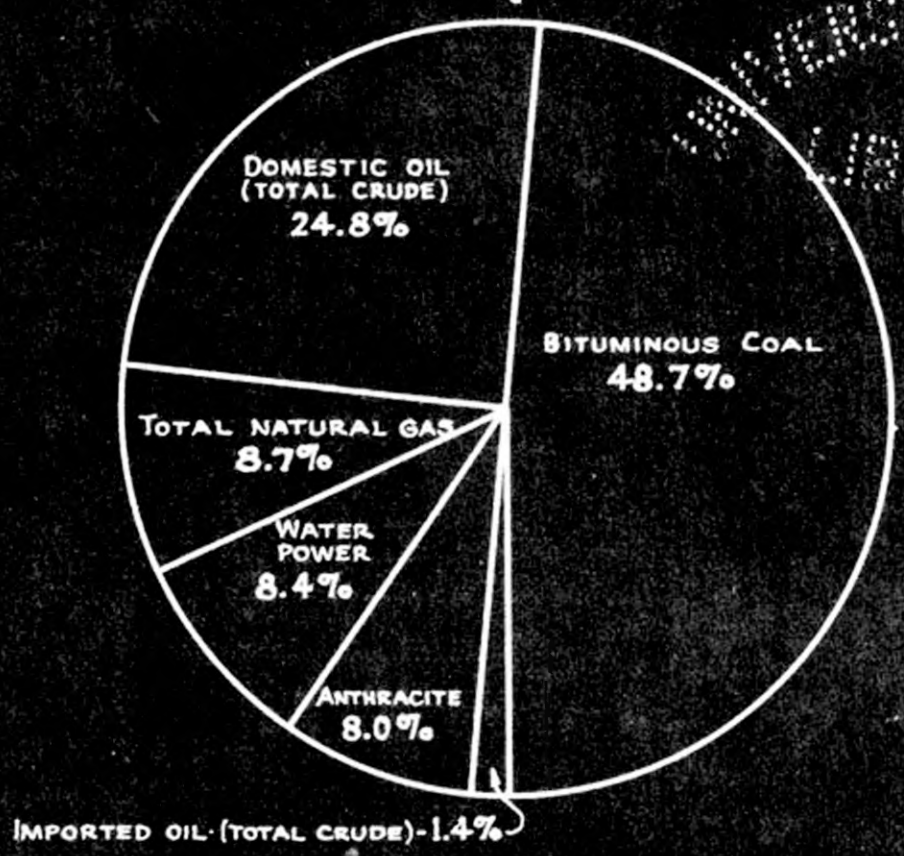
According to E. W. Parker (49) there are 13,130 square miles of land in Utah known to originally contain approximately 196,458,000,000 tons of workable coal.* Out of the 29 counties of the state, 17 are known to contain workable coal. At the end of 1933, about, 191,000,000 tons of coal have been mined, and if we assume one ton

*According to the figures given herein for the estimated world reserves, this amounts to about 2 per cent of the world's coal reserves.



DISTRIBUTION OF BITUMINOUS COAL CONSUMPTION IN U.S. - 1931

TOTAL CONSUMPTION OF COAL = 382,089,000 NET TONS



SOURCE OF ENERGY FROM MINERAL FUELS AND WATER POWER IN THE U.S. FOR 1931

TOTAL ENERGY CONSUMED = 20,557 TRILLION B.T.U.

FIG. 19

DATA FROM MINERAL RESOURCES U.S. 1931

loss for every two tons mined, the total exhaustion has been 178,500,000 tons, or about 0.09 of one per cent of the total available supply. The relative importance of each coal-producing county in 1931 is shown by the following table which gives the relationship by the percentage of the total coal mined.

Carbon County..... 88 per cent.

Emery County ..... 8 per cent.

Grand, Iron, Kane, Sevier,

Summit, Uintah ..... 4 per cent.

Figure 20 shows the outline of the Utah coal fields and the counties which they cover. The coal mined from Carbon and Emery Counties is a high grade bituminous coal containing 12,000 to 14,000 B.T.U. per pound. The Coalville Coal from Summit County is subbituminous and has a heating value ranging from 11,000 to 12,000 B.T.U. per pound. Because of its high moisture content, it crumbles and slacks on exposure to the air. There is a small area of anthracite in the New Harmony field and a relatively small area of cannel coal Southeast of Cedar City in the Colob-Kanab field. This coal yields from 65 to 70 gallons of oil per ton (50) and could "provide a permanent supply of low-priced city gas and diesel power-plant oil for Cedar City, also motor fuel and road oil for the National Parks area, and develop a new coal min-

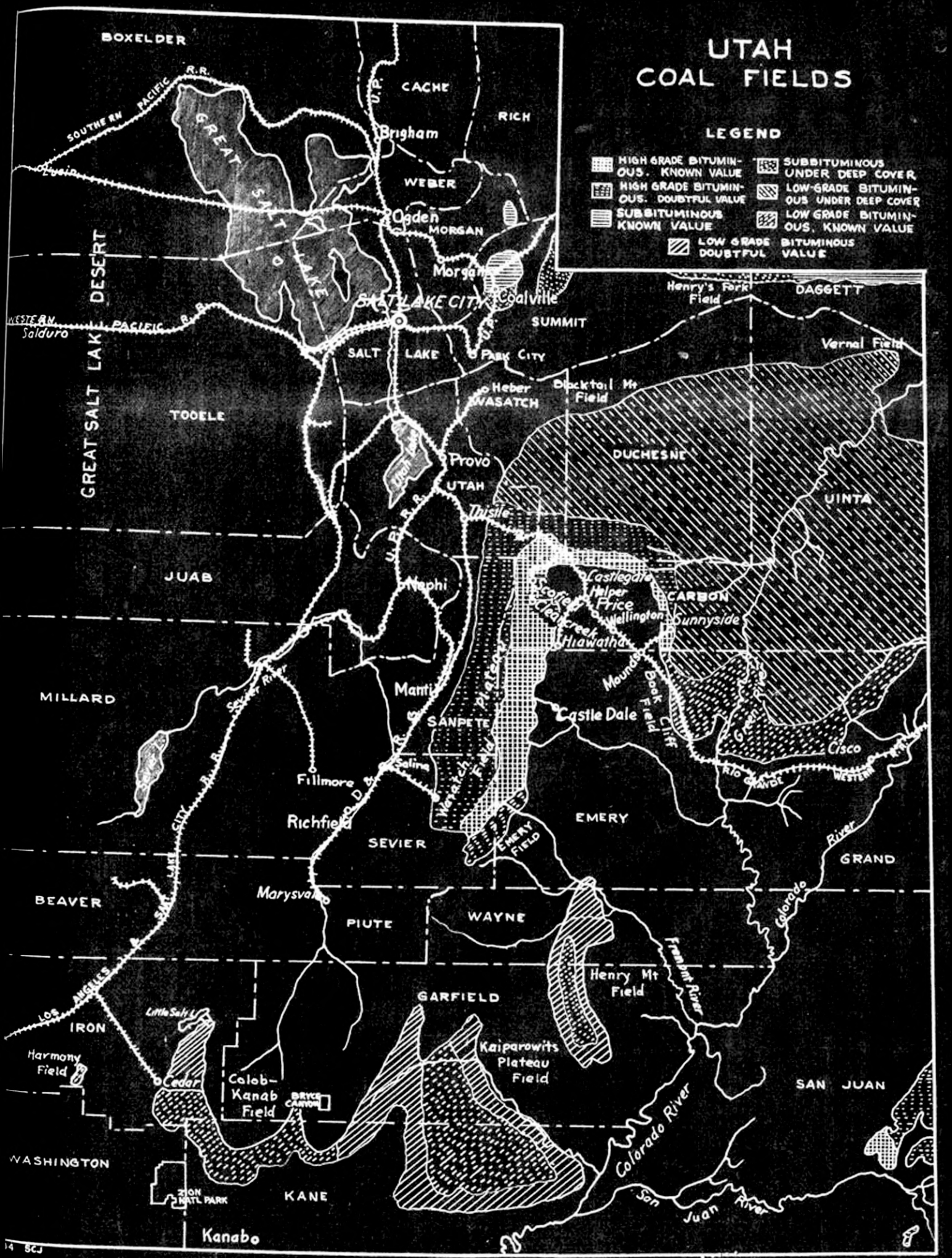
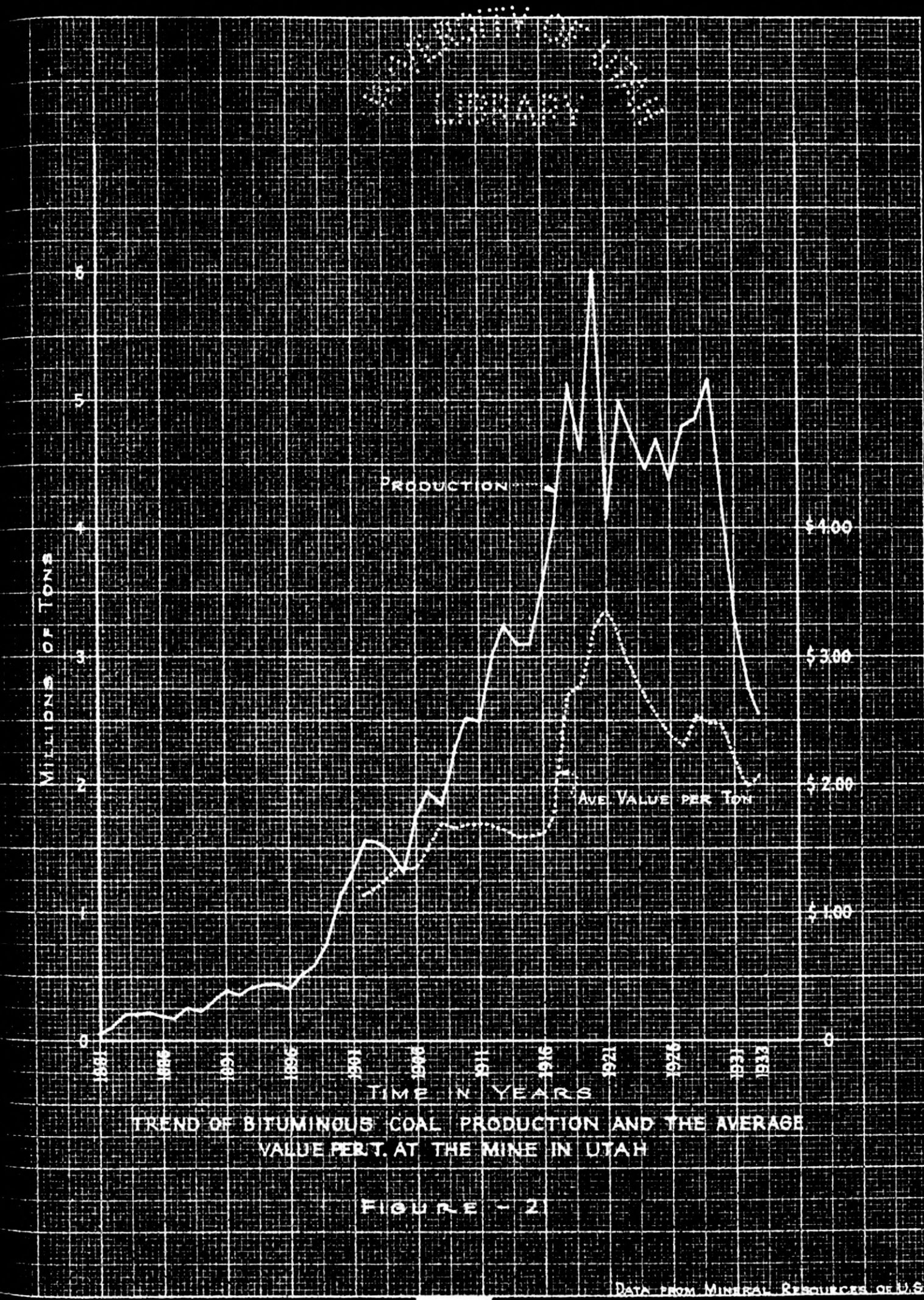


FIG. 20

ing industry of a remarkable coal with steady employment for labor in Southern Utah. " So far as is known, there is no lignite in the state.

Production of Coal in Utah. The trend of coal production in Utah can be clearly visualized by inspection of Figure 21 which shows the total tons produced yearly from 1881 to 1933, and the average price per ton at the mine for the period from 1902 to 1933. It is interesting to note that these curves closely follow the corresponding ones for the United States, as shown by Figure 18 . It is also apparent that during 1933 the coal operators of Utah were getting more money per ton of coal than the average for the United States. In 1932, Utah produced only 0.93 of one per cent of the country's supply of coal.

Remarks. In spite of the increasing use of substitute fuels, coal still is the most important source of energy today. Man has during the last 50 years come to depend upon coal as his main source of heat and electrical energy; as an absolute necessity in the production of pig iron which is so important in the development of the modern machine age; and for many other uses. Certainly the ills that are the present curse of the coal industry deserve to be eliminated, and will be if the industry is to progress and prosper.



TREND OF BITUMINOUS COAL PRODUCTION AND THE AVERAGE VALUE PER T. AT THE MINE IN UTAH

FIGURE - 2

DATA FROM MINERAL RESOURCES OF U.S.

APPENDIX II

PETROLEUM

Introduction. Petroleum, or earth oil, the magic fluid known from time immemorial, has found innumerable uses through the ingenuity of man. Practically every human activity of today is dependant upon petroleum.

Oil is the fuel and lubricant which speeds our transportation on land, upon and under the sea, and in the air.

Oil is the lubricant which makes possible the operation of our machinery, our radio, and the telephone.

Oil has made possible a higher tempo of life from that of a century ago, when a twenty-mile-an-hour steam car was the speed limit of transportation. It has made possible the extensive use of the automobile, the number of which, in the United States, has grown from a total of four to over twenty-six million in forty years.

With the growth of a giant industry having an investment of over twelve billion dollars, many men have concerned themselves as to how oil was formed. Is it still forming, and how can we look into the far future with assurance that oil will be available for our every need; or must we limit our use of motor cars in order to conserve our oil?

Society is a unit made up of integral parts which dovetail into one another and no one industry can develop or travel alone. Every achievement, whether it be progress in metallurgy, in engineering, in oil technology, or in any science or art, affects the rest of the social unit and is, in turn, limited by those other integral parts and also aided by them. Without the advancement of all industries, the oil industry could not have made the miracle of oil into today's universal necessity.

Geology and Theories of Oil Origin. In early times, petroleum was found by accident and used even less frequently than it was noticed. As people in general began to understand the value of this earth oil, it gradually became a necessity, and a growing demand required an increased supply. Soon man in many parts of the world was definitely seeking oil, looking carefully for any signs of its existence which may have escaped him.

From the geologist's point of view, petroleum may be located in any part of the world. It has been found in the Arctic Circle, in the jungles of Colombia and Borneo, on the equator, in the temperate zones of the United States and in many other parts of the world.

Present climatic conditions are not criteria as to whether oil may or may not be present in different areas

of the earth. The South and North Poles may be prolific oil sources years from now when the climatic conditions have shifted to livable ones for man. Petroleum deposits have been located in lakes, such as Maracaibo, Venzuela, or oceans, such as the Pacific at Summerland, California, in the desert land of San Joaquin Valley, or on a mountain side 13,000 feet up the slope of the Andes in Peru.

An oil pool is primarily a geologic phenomenon. It occurs within some kind of porous, reservoir rock, never as a lake of oil, and is definitely associated with some type of geologic structure. It exists because, in its relation to this structure, the escape of the crude oil in any direction is prevented by the impervious rocks which seal the reservoir.

Practically all strata making up the earth's crust contain hydrocarbons of different types, such as petroleum, gas and asphalt, whatever their age may be. For some rocks according to geologic time, were formed 1,200,000,000 years ago. However, not all strata contain oil in commercial quantities, for the world supply of petroleum is derived from sedimentary beds held in position by cap rock.

The theories of origin of petroleum may generally be divided into two groups: (1) inorganic or mineral origin, and (2) organic origin from once living matter. The

inorganic theories seem to account for the petroleum occasionally found in hard, igneous rocks or in meteors. It remains for the organic theories, however, to offer an explanation for the varied properties of different petroleum oils. Different types of animals or plants account for these numerous characteristics, according to the organic theorists.

There can be no question that the most striking evidence based upon geologic findings indicates that the source materials of petroleum are of animal and plant nature, for the oil fields of the world are the graveyards of trillions upon trillions of animals and plants. The body structures of fish, mollusks, crustaceans, formaminifera, diatoms, algae, and higher plant life, are present in the oil fields of the world. Even today low orders of marine life, having exactly the same body strutures as those which have been preserved through the ages, are forming bitumen-like substances on the beds of the streams or seas where they live.

A set of theories diametrically opposed to the organic ones, includes those that call for chemical reactions in the interior of the earth, and involving the information of petroleum from inorganic substances. In one case, the primary reaction involves the carbides of the metals such as calcium, sodium, or iron, which in contact with water, produce hydrocarbons of petroleum-

like characteristics. These reactions can be carried out in the laboratory, but it is problematical just how they took place in the bowels of the earth. One supposition of this theory is that the earth might contain free alkali metals. Carbon dioxide reacting at high temperatures with these alkali metals would form acetylides which, in contact with water form acetylene. This hydrocarbon, in turn forms petroleum-like bodies.

The cosmic theory of the origin of petroleum contends that it was formed during the solidification of the planet, trapped within primeval magma. This theory is strengthened by the finding of hydrocarbons in meteorites where life processes would appear to be excluded. Igneous rocks, basaltic lavas in volcanic areas, and volcanic material, have also been found to contain some hydrocarbons, but such a theory would account for only unusual and relatively small deposits of oil.

It must be emphasized, however, that no one theory has been found to cover all the occurrences and all the types of petroleum that we know. There is such a variation in qualities and characteristics of hydrocarbons and their derivatives that it is asking too much to expect one theory of petroleum formation to cover the entire earth's production.

Characteristics and Present Sources of Crude Oils.

All the crude oil produced in the world since the

beginning of the industry (22,000,000 barrels) would not fill a box one mile square and one mile deep. This vast quantity of petroleum is far from being uniform in appearance, quality, odor, or usefulness. Petroleum as it comes from the ground, or crude oil, as it is called, varies from a heavy, black, almost solid asphalt which must be heated to make it liquid enough to handle, to almost colorless, light liquids which are highly volatile and are almost entirely gasoline. Neither the geographical location of the oil field nor the geologic stratum from which the petroleum is obtained seem to account for these variations.

About the color of crude oils one can wax lyrical, for when seen by transmitted light they offer a variety of colors rivaling the rainbow. Crude oils in transmitted light show colors ranging from cherry, amber, yellow, green, and shades of red-brown to dense black, and, under reflected light, the gasoline crude oils show marvelous fluorescence. When crude petroleum is spread as a film on water, irridescent colors are reflected. This is a phenomenon which has proven to be valuable. It is an aid in tracing oil in areas where other indications are absent.

The range of colors encountered in crude petroleum is matched by the wide variety of odors attached thereto. Freshly obtained oils usually emit characteristic odors of one kind or another. Some are very pleasant, some nauseat-

ing; others are sweet, vile, offensive, or, in some cases, strange and exotic. Oils with an odor of sandalwood have been.discovered in Cuba, and one of the oils of Trinidad smells strongly of turpentine.

Petroleum from any of the different parts of the world is an extremely complex mixture of compounds made up primarily of carbon and hydrogen. .In addition to these two elements, the oil contains complex hydrocarbon derivitives of oxygen, sulfur, nitrogen, and metals, although these occur in much smaller amounts. There are at least four type-groups of hydrocarbons present in crude oils; namely, paraffins, aromatics, naphthenes, and olefins.

Crude oils are classified roughly as paraffinic, asphaltic, or semi-asphaltic. The gasoline content of crude oils ranges from zero per cent in the heavy oils to practically 100 per cent in the light crudes. In a similar manner, crude oils may range from zero per cent lubricating oil to nearly all lubricating oil, while some oils are practically all asphalt and others contain none.

Pennsylvania crude oils, the first to be exploited in the United States, are dominantly paraffin oils. Mid-Continent crudes are considered semi-asphaltic. Asphaltic oils come primarily from California, Texas, and Mexico, while the oils of Louisana, the Gulf Coast, and some from California are naphthenic. There are no sharp lines of

geographic distribution of different kinds of oil, for the same area may yield several types of crude oil.

Just as petroleum is found in all strata under the surface of the earth, from those of 600,000,000 years ago to the youngest formation, it is brought to the surface at points which are distributed over the face of the globe. Every continent, with the exception of Australia has its known oil-bearing areas, while the list of countries from which significant quantities of petroleum are obtained is surprisingly long.

In the Eastern hemisphere, there is oil in the East Indies, Burma, and India. There are rich fields of petroleum in Persia and in Iraq, and even some oil in Egypt, while Europe yields large quantities of oil from Russia, Poland, Germany, Czecho-Slovakia, and Roumania.

On the other side of the world, South America has a series of oil-producing areas from Trinidad, Venezuela, Colombia and Peru, to the Southern tip of Argentina. Mexico, too boasts of rich petroleum sources, but the United States supplies the bulk of the world's mineral oil from its numerous petroleum deposits.

From Pennsylvania and New York West to the Pacific Coast, and from Wyoming and Montana South to the Gulf of Mexico, is the measure of area over which oil is produced in commercial quantities in the United States. In fact,

nineteen states supply over 70 per cent of the petroleum of the world, the oil being of the most varied grade and types.

Refining of Petroleum. The speed of transportation, whether by airplane at 200 miles an hour, or by automobile or speed boat, rests upon fuel and lubrication. The billions of gallons of gasoline and lubricants required each year to operate these vehicles throughout the world, are obtained from crude oil by the primary operation of a highly developed mechanism of distillation and treatment.

Separating liquids from one another by boiling them and condensing their vapors, is an ancient art and goes back historically to at least the third century before Christ. In the first century A.D., Dioscordies hung flocks of wool in the vapors of boiling liquids and by wringing out the wool secured distillates.

One of the earliest evidences of obtaining oil by distillation is found in a British patent issued in 1694 for obtaining "pitch, tar and oyle out of a kind of stone" (probably oil shale).

The dominant product desired from petroleum was kerosene until about twenty-five years ago. As far as records show, the first petroleum still in the United States, which had a capacity of one barrel a day, was that erected by Samuel M. Kier in about 1855. Kier produced an illuminating oil which he sold through drugstores at $1.25

a gallon. The possibilities of Kier's discovery resulted in a number of plants being built by 1859. It is reported that Colonel Drake, after noting the operation of the refinery, was so impressed with its commercial possibilities that it played an important part in spurring him on to drill definitely for crude oil.

Prior to the development of the automobile, the gasoline produced in connection with the kerosene as the marketable product, was a drug on the market. After 1900 the two substances changed places and kerosene became difficult to dispose of. In 1899, from a barrel of crude there was obtained 5.4 gallons of gasoline and 24.2 gallons of kerosene. In 1930, gasoline represented 17.4 and kerosene only 2.2 gallons per barrel of crude.

The early distillation of Pennsylvania crude oil was carried out by boiling the oil in a tank resting over a furnace. The vapors escaped through a pipe outlet on top of the still to a cooling coil which consisted of a steel pipe placed within a box of water. Here the vapors were condensed to liquid form and then taken to various storage tanks in the refinery. The heat from the furnace was applied in such a way that the temperature of the oil was progressively raised to the boiling points of the different fractions of the original crude oil. The fraction boiling at the lowest temperature was gasoline. The next fraction

distilled over was kerosene, and the remainder, in this early operation, was marketed as lubricating oil.

This procedure has been much modified in Pennsylvania and elsewhere until, today, the refinery separates crude oil into many more fractions and converts it into the petroleum products demanded in this modern technological age.

Pennsylvania crude oils have a paraffin base and contain no asphalt. In modern distillation apparatus they are heated to boiling in a coil placed in a furnace. At the end of this coil is a giant tower, sometimes a hundred feet high with a diameter of eight feet or more, which sorts out the vapors it receives and delivers each to its individual receiver. Instead of distilling and redistilling one fraction, as in the old days, to produce a more refined oil, the modern pipe still does the job in one operation. One of the largest pipe stills in Pennsylvania handles about 5,000 barrels of oil per day.

The crude oils of the United States are not all like that from Pennsylvania. Some contain no gasoline, but have lubricating fractions; others are dominantly asphalt and contain very little lubricating oil. Hence, refining them to marketable products calls for individual modifications of Pennsylvania refinery practice.

The ordinary distillation of crude oil comprises only

the separation of one oil fraction from another. However, this process does not produce a sufficient quantity or proper quality of gasoline for the modern automobile. The modern car has reached a stage of development such that the oil industry is converting not only kerosene, gas and fuel oil, and in some cases the entire crude oil, but also nature's own gasoline, into high antiknock motor fuel. This is achieved by means of the cracking process.

Cracking makes an entirely different type of gasoline from that existing naturally in crude oil. Instead of merely boiling off the light fractions of petroleum, cracking subjects the oil to hight heat and pressure which breaks up the heavy hydrocarbon molecules into lighter molecules which burn evenly and without knock in the modern high-compression automobile engine.

The petroleum industry twenty years ago produced practically all its gasoline from ordinary distillation. Today cracked gasoline makes up over 40 per cent of the total 19,000,000,000 gallons of gasoline consumed in the United States during one year.

Uses of Petroleum Products. If the products from petroleum were suddenly removed from society, hunger would stalk the land because of the complete breakdown of mechanical means of transportation in the form of railroads, automobiles, and ships. The wheels of industry would cease turn-

ing and electrical illumination would be gone. Life in this modern age is most dependent upon oil in the form of gasoline, fuel and oil, and lubricating oils.

The speed of transporting farm products to the cities has been accelerated enormously by the aid of petroleum products. Motor trucks operated by gasoline are driven over asphalt roads at high speeds. Even the tires of the trucks are partially constructed of asphalt. Millions of pounds of high melting asphalt are blended with rubber to produce tires and other rubber goods so that the wearing quality is enormously enhanced.

Locomotives operate on fuel oil entirely in some localities and the rail ties are impregnated with petroleum so that deterioration from air, water and insects may be prevented.

Wherever civilized man congregates he is in an atmosphere of petroleum or its products. It is found in cigarette lighters, lotions and cold creams, and other cosmetics. Paraffin wax is used on the paper that protects our food products and in sealing the bottles of home-canned foods. It is found in varnish, lacquer, insect sprays, polishes, chewing gum, and medicinal oils.

Production of Petroleum. The world's production of petroleum in 1932 is estimated to have been 1,305,563,000 barrels. Compared to this the world production of 521,000 barrels for the years 1857-60 seems very small indeed. At

this early time the United States and Rumania were the only large producers. Venezuela began to attain prominance in petroleum production in 1917 when this country produced 120,000 barrels. In 1932 a total of 523,715,000 barrels or 40.1 per cent was produced outside of the United States and the three largest producers of the world in order were the United States, Russia, and Venezuela. The output of the Western Hemisphere was 75.3 per cent of the world total.

In the United States, since the year 1859, there have been over 850,000 wells drilled for oil, of which at the present time about 330,000 are producing. In October, 1932, the oil production in the United States was about 2,200,000 barrels per day, at an average rate of seven barrels per well. This average could be more than doubled were there an economic demand for more oil.

Oil Resources. The total amount of crude oil in the earth's crust is unknown, and unestimated, but it is assuredly a stagering volume. Geologists state that oil discovery is possible in 1,100,000,000 acres in the United States alone, or 56 per cent of its total land area. The contrast of this huge territory with about 2,500,000 acres which are now producing oil, makes it certain that new fields will continue to be discovered and that the oil resources of this country will prove ample for many years to come. It has been estimated that in the 35-foot seam of

limestone underlying Chicago there are over 7,000,000 barrels of oil to each square mile. What is true regarding the potential oil resources in the United States is probably true in even greater measure for the many countries of the world, where oil exploration has not been so thorough.

On the other hand, it must not be forgotten or disregarded that crude oil, along with the most precious of our other mineral deposits, is a valuable natural resource which must not be wasted. Despite the fact that there is no great danger of a shortage of mineral oil, the petroleum industry is finding that conservation is the better of exploitation.

It is estimated that only 20 per cent of the oil in the ground is recovered by the most used methods today. It is possible to extract this oil remaining in the reservoir rock by means of flooding or repressuring at an added expense to the oil producer. This oil alone could supply the world's needs for sixty years.

In view of the known crude oil reserves, the vast amount left underground by present production methods, the undiscovered fields that no doubt exist, and modern refining, an oil shortage, despite the gloomy prophets, is far in the future.

APPENDIX III

NATURAL GAS

General. Both because it has developed simultaneously with the oil industry, and because today one of its two chief products is casinghead or natural gasoline, the natural gas industry is of considerable interest to all of those who are interested in oil.

Gas was used in a small way before the discovery of oil in Pennsylvania, and in the history of every field has proven of immense value as a drilling fuel. In 1864 the supply of gas had developed to so great an extent that it could not be absorbed by the towns near the pools, and was used in the manufacture of carbon black. The gas industry was started in many sections of the country before oil was discovered. Occasionally gas districts were opened up in which the production of gas was not followed by the drilling of oil wells. Sections such as the Poteau gas district of Arkansas and the gas districts of central Pennsylvania are of this type. They are not, however, common.

Up until 1904 the value of the gasoline contained in many natural gases was not realized. In 1908, as a result of several years of research, the first compression

plant was built in West Virginia, and the production of natural gas gasoline began. Plants of this type numbered 250 by the end of 1912 and had further increased to 863 by 1921.

Natural gas, however, did not become of great importance, economically, until the years 1880-90. In that period many cities and towns in Pennsylvania, Ohio, and West Virginia were supplied with natural gas; new fields were opened up in Ohio and Indiana. The first paying gas wells in Kansas were drilled in 1887. In Texas the principal discoveries of gas were made in 1901 1903. In California, gas was utilized in 1890 but the large producting wells of that state were opened up in 1905-15, and drilled incidental to oil drilling operations.

Transportation. The first natural gas pipe line of consequence was built in 1876 to supply Titusville, Pennsylvania from a well 786 feet deep. This gas was transported five miles to the town through a two inch line. Today a vast network of pipe lines convey natural gas to a great number of cities in the country. Figure 22 shows the existing lines and the proposed lines for the year 1930. The figure also indicates the natural gas areas which correspond closely to the oil fields of the country.

Principal Pipe Lines and Fields of Natural Gas in the United States

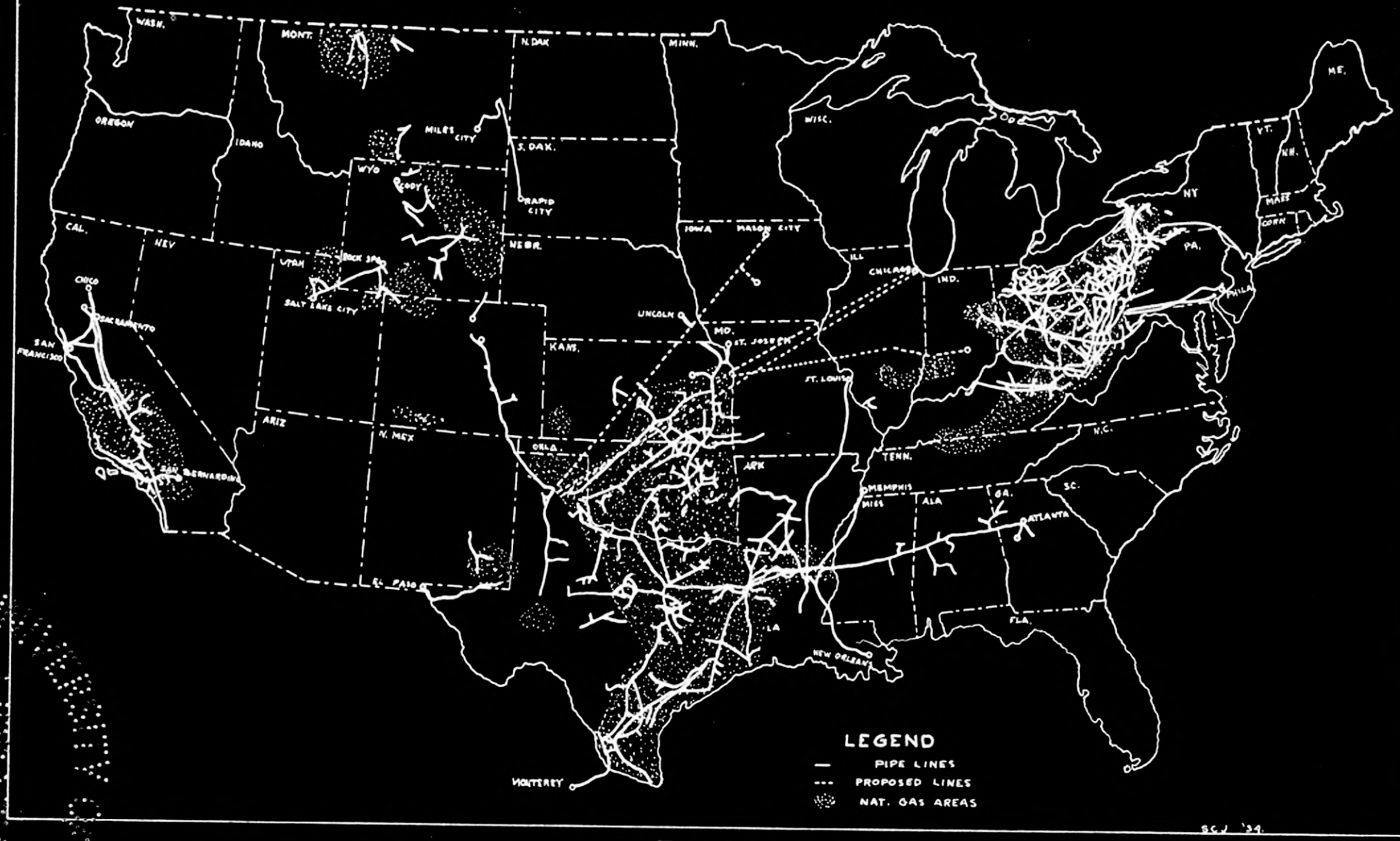


FIG. 22

Production. For the year 1922 there were 763 billion cubic feet of natural gas consumed in the United States. The production of gas reached 1637 billion in 1931 of which 381 billion were used domestically. The maximum production was reached in 1930 which was 1943 billion cubic feet.

APPENDIX IV

A.S.T.M. STANDARD METHOD OF TEST FOR CUBIC FOOT WEIGHT OF CRUSHED BITUMINOUS COAL

A.S.T.M. Designation: D 291 - 29

Scope:

1. This method is intended for the rather coarsely crushed coal, less than 1½ inch in size, such as is charged into coke ovens. It does not apply to powdered coal as used in boiler plants.

Apparatus

Cubic Foot Weight Box:

2. A box 12 by 12 inch inside dimensions shall be used. A box made of 1/8 inch sheet steel welded together and provided with handles, makes a very suitable cubic foot box and would weight approximately 35 pounds.

Sampling

Gross Sample:

3. For collecting gross samples of crushed bituminous coal, the procedure described in Sections 1 to 4, inclusive, and the directions preceding Section 1 of the Standard Method of Sampling Coal (A.S.T.M. Designation: D 21) of the American Society for Testing Materials shall apply. During the period of collecting the gross sample, the increments of the

sample shall be stored in a waterproof container with a tightly fitting cover in order to prevent the loss of moisture.

Laboratory Sample:

4. The gross sample of coal shall, as quickly as possible, to avoid loss of moisture, be thoroughly mixed and reduced by quartering, without crushing, to a laboratory sample of approximately 60 pounds in accordance with Sections 6 and 7 of the Standard Method D 21. The cubic foot weight should be determined immediately. If the determination of the cubic foot weight is not to be made immediately, the 60 pound laboratory sample should be kept in a waterproof container with a tightly fitting cover until the time for making the determination.

Procedure

5. The cubic foot weight box shall be placed on a suitable platform scale, weighed empty and then filled with crushed bituminous coal from the laboratory sample while the box is on the scale in order to avoid handling the heavy box of coal. The box shall be filled by means of a scoop or small shovel by allowing the coal to slide off the scoop or shovel from a height of 2 inches above the top of the box until the coal overflows on all sides of the box. Precaution should be

taken that none of the coal is dropped into the box so as to cause packing and that the cubic foot box is not shaken or tapped during filling. The excess coal shall be struck off by means of a straight edge without shaking or tapping the box. The box filled with coal shall then be weighed. The difference between the two weights to the nearest 0.1 lb. shall be reported as the weight of one cubic foot of the crushed bituminous coal.

NOTE: Aside from the character of the coal itself, moisture content and size of the coal are the two main factors which affect the cubic foot weight. A moisture determination and a sieve analysis of the coal should be reported along with the cubic foot weight for proper interpretation of the cubic foot weight.

APPENDIX V

STANDARD REAGENT SOLUTIONS FOR GAS ANALYSIS

Carbon Dioxide:

A stock solution is made up by dissolving 500 grams of potassium hydrate in 1 liter of water.

A portion of the solution is taken for the CO_2 bulb.

The gas sample is passed into the CO_2 bulb 4 or 5 times until a constant volume is obtained. The burette reading is recorded and the percentage of CO_2 calculated by dividing the cc. of gas absorbed by the number of cc. of sample taken.

Oxygen:

A solution of pyrogallate is made up by adding

1200 grs. KOH - 800 cc. H_2O

50 grs. Pyro - to 150 cc. H_2O

To each 350 cc. of KOH solution,

add 46 cc. of Pyro. solution.

The gas is passed from the burette to the oxygen bulb in the same manner as for CO_2 and the decrease in volume noted. The decrease divided by the samples gives the percentage O_2.

Carbon Monoxide:

For the determination of CO, a solution is made

up of 456 grams of Cu_2Cl_2 and 2400 cc. concentrated hydrochloric acid.

The adsorption bulbs are filled with this solution and reduced with a saturated solution of stannous chloride.

The carbon monoxide bulbs are different from the others in that the gas bubbles through the solution and two such bulbs are used in parallel, the gas being passed 4 or 5 times through each bulb.

With this solution there is usually a small amount of CO that does not absorb, so the correction is made later. The reading of the decrease in volume is recorded.

APPENDIX V1

EQUIVALENT PRICES FOR COAL AND NATURAL GAS

Comparison of Utah Coal of 13,000 B.T.U. per pound and gas of 1,000 B.T.U. per cu. ft.

Method for calculating equivalent prices:

2,000 lbs. x 13,000 = 26,000,000 B.T.U./ ton of coal

26,000 cu. ft. x 1,000 = 26,000,000 B.T.U./26 M's of gas

Therefore, 1 ton of coal = 26 M's of natural gas on 100% heating basis.

With 50% as the average heating efficiency of coal as used in residences; and 70% as the average heating efficiency of gas as used in house heating:

1 ton of coal will deliver 13,000,000 B.T.U., and
26 M's of gas will deliver 18,200,000 B.T.U., or
18.6 M's of gas will deliver 13,000,000 B.T.U.
Therefore 1 ton of coal = 18.6 M's of natural gas on the basis of heat received.

Example:

If coal costs $7.50 per ton, gas must sell for

$\frac{750}{18.6}$ or 40.3 cents per M.

TABLE OF EQUIVALENT PRICES FOR NATURAL GAS AND COAL

Assume: 70% as the efficiency obtained with

1,000 B.T.U. gas, and coal prices and heating efficiencies as shown.

Coal Cost	Equivalent Prices Per M of Natural Gas Combustion Efficiences for coal of:-					
Per ton	40%	50%	60%	70%	80%	90%
Dollars	Cts/M	Cts/M	Cts/M	Cts/M	Cts/M	Cts/M
3.00	20.0	16.1	13.6	11.5	10.0	9.0
3.50	23.4	18.8	15.8	13.4	11.7	10.5
4.00	26.7	21.5	18.1	15.5	13.3	12.0
4.50	30.0	24.2	20.4	17.4	15.0	13.6
5.00	33.4	26.9	22.6	19.2	16.7	15.0
5.50	36.7	29.6	24.9	21.1	18.3	16.5
6.00	40.0	32.3	27.2	23.0	20.0	18.0
6.50	43.3	34.9	29.4	24.9	21.6	19.6
7.00	46.6	37.6	31.7	26.9	23.3	21.0
7.50	50.0	40.3	33.9	28.8	25.0	22.5
8.00	53.4	43.0	36.2	30.7	26.7	24.0
8.50	56.7	45.7	38.5	32.6	28.3	25.6
9.00	60.0	48.4	40.7	34.5	30.0	27.1
9.50	63.4	51.0	43.0	36.4	31.9	28.6
10.00	66.7	53.8	45.2	38.4	33.4	30.1

BIBLIOGRAPHY

1. Gates, Susa Young and Widtsoe, Leah D., "The Life Story of Brigham Young", N. Y., 1930.

2. Tullidge, Edward W., "The History of Salt Lake City and its Founders", Salt Lake City, 1850.

3. Kirke, "Handbook of Physiology", 2d Ed. N.Y., 1910.

4. Azbe, Victor J., "Rationalizing Smoke Abatement", Third International Conference on Bituminous Coal, Nov. 16 - 21, 1931.

5. Ibid.

6. Obermeyer, Henry, "Stop That Smoke", N. Y., 1933, Page 19.

7. Ibid. p. 20

8. Ibid, p. 24.

9. Azbe, Victor J., "Rationalizing Smoke Abatement", Third International Conference on Bituminous Coal, Nov. 16 - 21, 1931.

10. Flagg, Samuel B., "Smoke Abatement and City Smoke Ordinances. U.S.B.M., Bull. 49, 1912.

11. Wyer, Samuel S., "Fundamentals of the Smoke Nuisance" Fuel-Power-Transportation Educational Foundation. Jan.1929

12. Hood, O. P., "The Smoke Problem", U.S.B.M., R. I. 2323,1922.

13. Gebhardt, G. F., "Steam Power Plant Engineering, 1928.

14. "Comparative Data on Solid, Liquid and Gaseous Fuels", Committee of Ten Coal and Heating Industries. Educ. Bull. No. 6, Dec. 1932.

15. Ibid.

16. Ibid.

17. Gebhardt, G. F., Steam Power Plant Engineering, 6th Ed., N.Y., 1928.

18. Gudmundsen, Austin, "Nine Years of Smoke - Abatement Work at Salt Lake City", U.S.B.M., R. I. 3001 - April, 1930.

19. Monnett, Osborn; Perrott, G. St. J.; and Clark, H. W., "Smoke - Abatement Investigation at Salt Lake City, Utah", U.S.B.M., Bull. 254 - 1926.

20. Orrok, Geo. A, and Trask, W. H., "Salt Lake City's Fuel and Smoke Problem", A.S.M.E. Trans., Vol. 51, 1929. Fsp - 51 - 48 - 375.

21. Duke, Otto, "Investigation of Coal Burning Equipment Designed to Burn Utah Coal Without the Emission of Smoke", Master's Thesis, University of Utah, 1932.

22. Ketchum, R. B., "Report to Joint Smoke Abatement Committee of Salt Lake City on the Feasibility of a Pilot Plant for Treating Coal by the Karrick Process", October 28, 1932.

23. Belden, A. W., "Metallurgical Coke" - U.S.B.M., T. P. 50., 1913.

24. Gentry, Frank M., "The Technology of Low-Temperature Carbonization", Baltimore, Maryland, 1928.

25. Lewes, Vivian Byorn, "Carbonization of Coal", London, 1912.

26. Parr, S. W., "Low-Temperature Carbonization of Coal", Industrial and Engineering Chemistry, Vol. 21, Feb., 1929, p. 164 - 168.

27. Burgess and Wheeler, The Chem. Soc. Trans., V. 97, 1910, p. 1917; Vol. 99, 1911, p. 649.

28. Fieldner, A. C., "Recent Developments in Coal Utilization", Minerals Yearbook 1932-33. p. 433.

29. Ashley, Geo. H., "Cannel Coal in the United States", U.S.B.M., Bull. 659, 1918, p. 42 - 44.

30. Fieldner, A. C., "Low-Temperature Carbonization of Coal", U.S.B.M., Tech. Paper 396, 1926.

31. Hall, R. Dawson, "Largest Distilled - Coal Plant in the World", Coal Age, Vol. 34, April 1929, p. 229-30.

32. Brownlie, David, "The Coalite Process", Chemistry and Industry, Vol. 48, Dec. 1929, p. 1243-46.

33. "The Illingworth Low-Temperature Carbonization System" Colliery Guardian, Vol. 144, N. 3718, April 1, 1932, p. 629.

34. Wheeler, R. V., "The Salerni System of Low-Temperature Carbonization", Third International Conference on Bituminous Coal, 1931, Vol. 1, p. 371-390.

35. Toltz, Max., Carbonization - Plant using the "Lurgi" Process., A.S.M.E. Trans. Vol. 52, 1930- Fsp. 52-12.

36. McQuade, J. D., "Low-Temperature Carbonization as an Aid to the Coal Industry", Explosives Engineer, June 1932, p. 174-75.

37. Wadleigh, F. R., "The Need for Coal Research", A.S.M.E. Trans. Vol. 50 - Fsp 50-33.

38. Kinney, Corliss R., Burton, Theodore M., and Karrick, L. C., "A Study of the Cracking of Low-Temperature Utah Coal Tar." The Mining Review, Jan. 1932.

39. Karrick, L. C., "Salt Lake's Smoke and Smokeless Fuel Problem." The Mining Review, August 15, 1927.

40. White, David and Thiessen, Reinhardt.,"The Origin of Coal" U. S. B. M. Bull. 38, 1913.

41. Tarr, W. A."Introductory Economic Geology" New York, 1930.

42. Heinrich and Ries,"Economic Geology" p. 11.

43. Thom, W. J. Jr.,"Petroleum and Coal, The Keys to the Future" Princeton, 1929.

44. Ashley, G. H.,"The Maximum Rate of Deposition of Coal." Econ. Geo., vol. 2, 1907, p. 34-37.

45. Parker, E. W., Holmes, J. A., Campbell, M.R., "Report on the Operation of the Coal-Testing Plant of the United States Geological Survey at Louisiana Purchase Exposition,"St. Louis, Mo. 1906. Part I.

46. Campbell, M. R., " The Coal Fields of the United States"., U. S. G. S. Prof. Paper 100-a. 1929.

47. Campbell, M. R., "Analysis of Coal Samples from Various Fields in the United States." U.S.G.S. Bull. 541, 1914. pp.491-526.

48. Allen, C. A., "Analysis of Utah Coals". U.S.B.M. T.P. 345, 1925.

49. Parker, E. W., "Coal", U. S. G. S. Mineral Resources 1910, Part 2, page 206.

50. Jacobsen, S. C., and Carter, Geo. W., "The Engineering Factors Relating to the Utilization of the Cannel Coals of Southern Utah." Bachelor of Science Thesis, University of Utah, 1933.

51. References to Appendices II and III:

Egloff, Gustav, "Earth Oil", 1933.
The Mineral Industry During 1932, A.I.M.M.E. Vol. 41, 1932.